

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
25 November 2004 (25.11.2004)

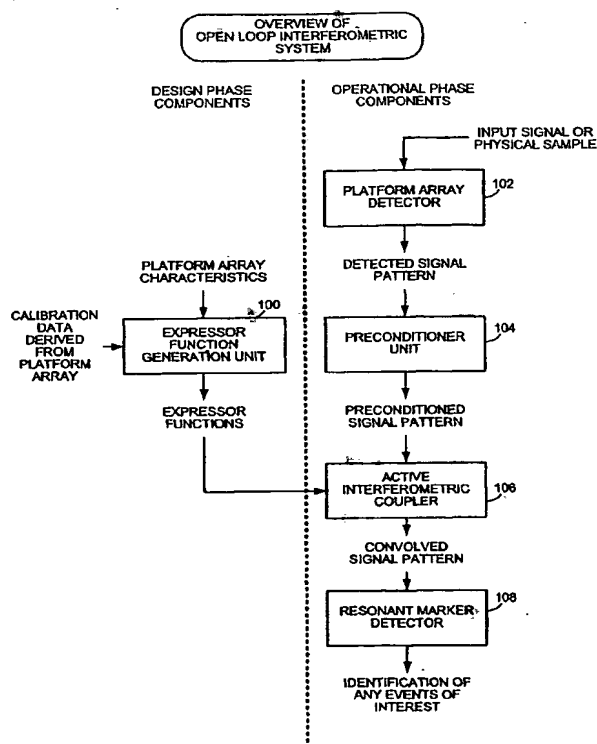
PCT

(10) International Publication Number
WO 2004/102456 A2

- (51) International Patent Classification⁷: **G06F 19/00**
- (21) International Application Number:
PCT/US2003/021525
- (22) International Filing Date: 9 July 2003 (09.07.2003)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
60/395,074 9 July 2002 (09.07.2002) US
60/399,227 29 July 2002 (29.07.2002) US
60/408,057 3 September 2002 (03.09.2002) US
60/408,844 5 September 2002 (05.09.2002) US
60/440,253 15 January 2003 (15.01.2003) US
- (71) Applicant (for all designated States except US): VIAL-OGY CORP. [US/US]; 2400 Lincoln Avenue, Altadena, CA 91001 (US)
- (72) Inventor; and
- (75) Inventor/Applicant (for US only): GULATI, Sandeep [US/US]; 5467 La Forest Drive, La Canada Flintridge, CA 91011 (US).
- (74) Agent: KUKKONEN, Carl, A., III; 2400 Lincoln Avenue, Altadena, CA 91001 (US).
- (81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.
- (84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE,

[Continued on next page]

(54) Title: ACTIVE INTERFEROMETRIC SIGNAL ANALYSIS IN SOFTWARE



(57) Abstract: Techniques are provided for performing active interferometric signal analysis in software. The techniques exploit expressor functions designed to extract spectral invariants of events of interest associated with an arrayed platform device used to detect the signal pattern to be analyzed. Various techniques for generating expressor functions are also provided. Depending upon the implementation, the techniques provide for both detection and quantitation analysis by exploiting either constructive or destructive interferometric analysis using reverberant convergence to detect resonance events. The techniques achieve software emulation of wave-particle interactions and wave-wave interactions and can operate in either the frequency domain or the phase domain. The techniques may be used for analyzing static spatial systems, static data from arrayed measurement platforms, dynamical systems, spatio-temporal systems or plasma systems.

WO 2004/102456 A2

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

- *without international search report and to be republished upon receipt of that report*

ACTIVE INTERFEROMETRIC SIGNAL ANALYSIS IN SOFTWARE

Field of the Invention

The invention generally relates to active signal analysis systems, and in particular,
5 interferometric signal analysis systems.

Related Applications

This application is a continuation-in-part of U.S. Pat. App. No. 09/913,132, filed Aug. 9, 2001, entitled "Method and System for Signal Detection in Arrayed
10 Instrumentation Based on Quantum Resonance", which is a national stage application of PCT Application No. US00/04076 filed on Feb. 17, 2000, which claims priority from U.S. Pat. App. No. 09/253,789, now U.S. Pat. No. 6,136,541, filed on Feb. 22, 1999, entitled "Method and Apparatus for Analyzing Hybridized Biochip Patterns using Resonance Interactions Employing Quantum Expressor Functions, all of which are hereby fully
15 incorporated by reference". Also incorporated herein by reference in their entirety are the following patents based on applications filed contemporaneously with U.S. Pat. App. No. 09/253,789: U.S. Pat. No. 6,142,681, entitled: "Method and Apparatus for Interpreting Hybridized Bioelectronic DNA Microarray Patterns Using Self-scaling Convergent Reverberant Dynamics" and U.S. Pat. No. 6,245,511, entitled "Method and Apparatus for
20 Exponentially Convergent Therapy Effectiveness Monitoring Using DNA Microarray Based Viral Load Measurements". Also incorporated herein by reference in their entirety are the following provisional patent applications: U.S. Pat. App. No. 60/395,074, filed on Jul. 9, 2002, entitled "Active Signal Processing Technique Using Resonance Interferometry". U.S. Pat. App. No. 60/399,227, filed on Jul. 29, 2002, entitled "High-
25 Throughput Quantitation of Signals from Arrayed Platforms Using Resonance Interferometry" U.S. Pat. App. No. 60/408,057, filed on Sep. 3, 2002, entitled "Technique for Analysis and Quantitation of Arrayed Information Structures". U.S. Pat. App. No. 60/408,844, filed on Sep. 5, 2002, entitled "System and Method for Analysis and Quantitation of Arrayed Platforms". U.S. Pat. App. No. 60/440,253, filed on Jan. 15, 2003,

entitled "Technique for Detection and Quantitation of Arrayed Platform Signals".

Background of the Invention

1. Overview of Passive and Active Interferometric Signal Analysis

5 Interferometric analysis has proven useful for performing signal analysis, particularly for detecting events of interest within signal patterns, such as within a two-dimensional image. One example of interferometric analysis involves irradiating a moving object, such as an aircraft, with radar pulses, that interact with the object and interfere with one another and which are then reflected back to a sensing device such as an antenna.

10 Signals received by the antenna are compared against signals originally transmitted in an effort to detect a unique spectral signature of the object so as to identify the object. This form of interferometric analysis is referred to as "active analysis", because signals used to irradiate the event of interest interact with the object and with other signals to actively modify the resulting interference pattern. In other words, the system being analyzed is

15 actively modified. In the case of radar, electromagnetic fields surrounding the event of interest are actively modified.

An alternative type of signal analysis is "passive analysis" wherein signals that have already been detected are processed in an effort to identify events of interest therein. Examples include filtering images in an attempt to enhance features therein. These

20 techniques are deemed to be passive because no noise or other signals are added into the system being analyzed. More specifically, passive interferometric analysis typically involves the manipulation of observed intensity patterns or phase information without the addition of noise or other signals. Often, passive analysis systems exploit parametric methods such as matched filter techniques, maximum a-posteriori (MAP) techniques,

25 maximum likelihood estimator (MLE) techniques, singular value decomposition (SVD), classical Fourier analysis, parametric distributional clustering (PCA), or median filter variants. Non-parametric methods may be employed as well. In addition, quantitation and clustering techniques may be employed such as "soft-computing" and its variants which include neural networks, fuzzy logic systems, and Bayesian inferencing systems.

Although a wider range of passive analysis techniques have been exploited, each requires that the observed signal have an intensity greater than the intensity of the background signal in which it appears. In addition, the analysis system must properly estimate the background signal and to properly estimate any variability in the background signal. In some cases, spread spectrum (S-S) amplitude correlation is provided with background subtraction, and scaling and normalization is employed to compensate for detector nonlinearities. Hence, there are various limitations to passive analysis, particularly the inability to detect signals having an intensity less than or near to the intensity level of the background.

Insofar as the analysis of hybridized biological microarray patterns is concerned, heretofore, passive analysis has been the only form of analysis performed. Briefly, a signal pattern output from a biological microarray is normalized to compensate for dye, scanner, or array effects. Then an estimate is made as to the background signals at feature, transcript or chip levels. The background is then subtracted from the foreground and a ratio of foreground minus background is calculated to quantitate a differential expression representative of patterns of interest. Often, this calculation is performed using channel ratios. In any case, examples of passive analysis of hybridized digitized image patterns include PCA, SVD, MLE, hidden Markov Model (HMM), and various statistical approaches. As the technique is passive, it is subject to the limitations summarized above, in particular, only hybridized transcripts with genes above the estimated background can be detected. In addition, high call variability in targets with low expression levels arises and high CV in fold change computations occurs. Skewed results can arise when dealing with platforms or protocols having a limited dynamic range. Typically, passive hybridization analysis techniques require vast amounts of data and exemplars to allow refinement of statistics driving the call analysis. Heretofore, efforts to improve the accuracy and reliability of passive techniques for analyzing hybridized digitized images involve wet signal amplification and biological enhancements. Computational enhancements of the passive analysis have been fairly minimal.

Thus, heretofore, computer systems have been largely limited to performing

passive analysis whereas active analysis is largely performed only by hardware systems.

2. Hardware-Based Active Signal Analysis

With hardware-based active interferometric signal analysis, external excitation is provided to the system being analyzed while the system is being analyzed to provide an interaction that generates additional information or provides some change in a qualitative property of the system. Typically, the external excitation involves some form of noise injection, which results in a nonlinear coupling between the noise and events of interest within the system being analyzed, which enhances those events. As noted, one example of active signal processing (ASP) is radar wherein the signal being injected into the system being analyzed is the radar signal. Another example is the superconducting quantum interferometric device (SQUID), which utilizes the quantum effects of superconductivity to detect magnetic fields. Other examples include imagery intelligence (IMINT), signals intelligence (SIGINT), electronic intelligence (ELINT) devices. In addition, active signal processing has been applied to femto-lasers. While these hardware-based systems provide enhanced signals in some circumstances, such systems are expensive to build and operate and can only physically manipulate or generate very specific types of signals.

3. Stochastic Resonance Techniques

Another exemplary active system or technique that has been implemented in software is stochastic resonance wherein noise is applied to an image or a system being analyzed to improve its output signal-to-noise ratio (SNR). With stochastic resonance, a detector is modeled in terms of a bistable nonlinear dynamic system, which is enhanced by applying additive random noise element and a periodic sinusoidal forcing function. Stochastic resonance occurs when the SNR passes through a maximum as the noise level is increased. By properly selecting the amount of noise being applied, events of interest can be enhanced so that signals below background can be detected.

Traditionally, stochastic resonance is employed using a classical noise source such as a standard Gaussian noise pattern. Alternatively, however, stochastic resonance may be employed using some form of quantum noise. In this regard, it has been shown that

irradiation of a bistable system with a weak resonance laser field induces long-lived coherent tunneling motion whose amplitude exhibits a quantum stochastic resonance (QSR) as a function of the two-level-system relaxation rate and the field strength (See Makarov DE. Makri N. "Stochastic resonance and nonlinear response in double-quantum-well structures" Physical Review B. 52(4):R2257-R2260, 1995 Jul 15). Essentially, QSR is an enhancement of the response of a driven quantum mechanical system by quantum noise.

In any case, heretofore, traditional stochastic resonance and QSR have only been applied to point dynamical systems, i.e. to systems providing only a signal data point varying in time. One other technique for enhancing stochastic resonance is so-called array-enhanced stochastic resonance (AESR), which extends stochastic resonance to 2-D dynamical systems, though still limited to static systems. Although an improvement, AESR is typically limited to the analysis of systems with relatively few degrees of freedom.

Thus, most conventional active signal analysis systems are not implemented in software and those that have been implemented in software typically have significant limitations. Accordingly, it would be desirable provide new or improved techniques for implementing active signal processing in software and it is to these ends that aspects of invention are drawn. By implementing active signal analysis in software, all of the advantages associated with software systems over hardware systems can be exploited, including lower cost, increased flexibility, increased robustness, portability, etc.

More specifically, it is desirable to provide an active signal processing system implemented in software capable of detecting events of interest in spatial, temporal or spatio-temporal systems within a combinatorial state space wherein the state space is discrete and continuous and wherein background noise is nonstationary. Ideally, the system would be capable of analyzing signals received from a wide variety of arrayed platform detector configurations including linear, arrayed, spectral, and time-varying and can handle N -attribute systems. Moreover, ideally, the improved system would be capable of analyzing signals with a signal to background ratio of 10^{-4} . Insofar as the analysis of

biological samples applied to a microarray platform is concerned, the system or technique would ideally be capable of detecting and quantitating specific hybridization (e.g., genomic events) and specific binding events (e.g., proteomic events). Insofar as genomics is concerned, the system should be capable of processing data from a high-density gene expression microarrays (i.e. array is providing 10^2 to 10^6 spots per array) and which represents discrete, spatially indexed systems having high probe densities (i.e. from 10^6 to 10^9 probes per spot).

Summary of the Invention

10 In accordance with the invention, techniques are provided for performing active interferometric signal analysis in software. Depending upon the implementation, the techniques provide for both detection and quantitation analysis by exploiting constructive or destructive interferometric analysis (or a combination of constructive and destructive interferometric analysis) using reverberant convergence to detect resonance events. The techniques achieve software emulation of wave-particle interactions and wave-wave interactions and can operate in either the frequency domain or the phase domain. The techniques may be used for analyzing static spatial systems, static data from arrayed measurement platforms, dynamical systems, spatio-temporal systems or plasma systems.

15 Briefly, the techniques exploit expressor functions designed to reject any interfering noise or background clutter from possible events of interest within arrayed data to be analyzed. More specifically, the expressor functions are designed so as to extract spectral invariants of possible events of interest associated with the array device used to detect the arrayed data. Various aspects of the invention are directed to the generation of the expressor functions. Typically, the expressor functions are designed to incorporate some form of non-Gaussian noise, such as quantum noise, pseudorandom noise, polycyclostationary noise, cyclostationary noise, stationary noise, non-stationary noise or a systemic bias. Preferably, prior to the application of the expressor function to arrayed data, the array is pre-conditioned so as to convert the arrayed data to a spectral domain in which spectral harmonics parameterize events of interest to a pre-determined dynamical system.

Preconditioning may be performed by applying a preconditioning function incorporating, e.g., a 1-D Fourier function, a 2-D Fourier function, an N-D Fourier function, a time division multiplexing (TDM) function, a wavelength division multiplexing (WDM) function, a frequency division multiplexing (FDM) function, a radial bias function, a
5 wavelet kernel function, a fractal function, or a soliton function. The arrayed data itself may be the form of a spatial 1-D array, a spatial 2-D array, a spatial point emitter array, a temporal point emitter array, a spatio-temporal point emitter array, a spectral point emitted array or a virtual array constructed by combining spatial separate point emitters.

In accordance with an exemplary method, a technique is provided for actively
10 analyzing a signal pattern representative of arrayed data to identify events of interest therein. A signal pattern representative of arrayed data is input and resonance patterns are generated based on interference between synthetic noise and the signal pattern. Next, resonances within the resonance patterns associated with events of interest are detected. Preferably, the signal pattern is preconditioned prior to the step of applying synthetic noise
15 to the signal pattern.

In a first exemplary system embodiment, also referred to herein as an "open loop interferometric system", a system is provided for analyzing an arrayed signal pattern generated by an arrayed platform device to identify events of interest within the signal pattern. The system includes an expressor function input unit for inputting previously
20 generated expressor functions capable of extracting spatial, spatio-temporal or spectral invariants of events of interest associated with the particular arrayed platform device being used. The system also includes a preconditioning unit for preconditioning the arrayed signal pattern. An active interferometric coupler operates to convolve the preconditioned arrayed signal pattern and the expressor functions so as to interferometrically enhance
25 portions of the preconditioned pattern associated with events of interest, if any, present within preconditioned pattern. The system also includes a resonance marker detector for identifying the occurrence of events of interest within the convolved signal pattern.

In a second exemplary system embodiment, also referred to herein as a "goal-directed interferometric system", the system for analyzing an arrayed signal pattern

includes an expressor function input unit for inputting previously-generated expressor functions and an adaptive interferometric coupler for preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain while simultaneously convolving the signal pattern and the expressor functions so as to
5 interferometrically enhance portions of the signal pattern to identify events of interest, if any, within the signal pattern.

In a third exemplary system embodiment, also referred to herein as a "self-organizing interferometric system", the system includes a preconditioner for preconditioning the arrayed signal pattern and an expressor function adaptation unit for
10 generating preconditioned expressor functions based on input canonical expressor functions (i.e. general expressor function not associated with the particular platform being used) and based on a preconditioned signal pattern while interferometrically enhancing portions the preconditioned signal pattern so as to identify events of interest, if any, within the signal pattern.

15 In a fourth exemplary system embodiment, also referred to herein as an "iterative interferometric system", the system includes an expressor function input unit for inputting previously-generated expressor functions derived for the platform being used, a preconditioner for preconditioning the arrayed signal pattern and a iterative convolution coupler. The system also includes an adaptive controller unit for controlling the coupler to
20 iteratively and selectively convolve the expressor functions to a preconditioned signal pattern until a predetermined degree of convergence is achieved so as to identify events of interest within the enhanced signal pattern.

A variety of techniques are set forth for performing active signal analysis in software. Method, system and computer product embodiments are provided.

25

Brief Description of the Drawings

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and

wherein:

FIG. 1 is a block diagram providing an overview of system components of the first exemplary embodiment of the invention (the open loop interferometric system), which provides separate expressor function generation unit, preconditioner, active interferometric
5 coupler and resonant marker detector components;

FIG. 2 is a flowchart providing an overview of method steps for the first exemplary embodiment of the invention;

FIG. 3 is a block diagram providing an overview of system components of the second exemplary embodiment of the invention (the goal-directed interferometric system),
10 which provides an adaptive interferometric coupler;

FIG. 4 is a flowchart providing an overview of method steps for the second exemplary embodiment of the invention;

FIG. 5 is a block diagram providing an overview of system components of the third exemplary embodiment of the invention (the self-organizing interferometric system),
15 which provides a expressor function adaptation unit;

FIG. 6 is a flowchart providing an overview of method steps for the third exemplary embodiment of the invention;

FIG. 7 is a block diagram providing an overview of system components of the fourth exemplary embodiment of the invention (the iterative interferometric system),
20 which provides a adaptive controller for iteratively controlling a separate iterative interferometric coupler;

FIG. 8 is a flowchart providing an overview of method steps for the fourth exemplary embodiment of the invention;

FIG. 9 is a graph illustrating combinations of arrayed data signal patterns that may
25 be processed by any of the embodiments of the invention; and

FIG. 10 is a graph illustrating combinations of preconditioning functions and expressor functions that may be used in connection with any of the embodiments of the invention;

FIG. 11 is a graph illustrating an exemplary platform array detector and active

interferometric analysis system that may exploit the invention;

FIG. 12 is a graph illustrating various platform array detectors that may be used in connection with any of the embodiments of the invention;

FIG. 13 is a graph illustrating the structure of an exemplary microarray platform
5 that may be used to generate arrayed data for use by any of the embodiments of the invention; and

FIG. 14 is a flowchart summarizing the overall method of the invention, at least in accordance with an exemplary embodiment thereof.

Detailed Description of Exemplary Embodiments

With reference to the remaining figures, exemplary embodiments of the invention will now be described.

5 A. OPEN LOOP INTERFEROMETRIC SYSTEM

1. Overview

FIG. 1 illustrates, at a high-level, exemplary system components for the first exemplary implementation of the invention. Components employed only during a design phase are shown on the left; components employed during the actual analysis of an input
10 signal are shown on the right. Briefly, during the design phase, expressor function generation unit 100 generates one or more designer expressor functions based upon the specific characteristics of a platform array detector 102 to be used to detect signal patterns to be processed and also based on calibration data derived from platform array 102. The calibration data is generated based on known events of interest. That is, input signals or
15 physical samples containing known events of interest are applied to the detector to generate the calibration data. In one example, the platform array detector is a genomic biochip/microarray and the calibration data is derived from a biological sample containing known gene expressions. The characteristics of the platform array detector that are input by the expressor function generation unit include both the layout of the array as well as its
20 coherent noise or background signal characteristics. Once the expressor functions have been generated for the particular platform array detector based on the calibration data, the design phase is complete and, thereafter, the expressor function generation unit is no longer required unless an alternative platform array detector is employed.

Components employed during the actual operational phase of the system include
25 the aforementioned platform array detector 102 that generates a detected signal pattern and a preconditioner unit 104 that preconditions the detected signal pattern so as to convert the signal pattern to a spectral domain (for an example of a technique for transforming the signal pattern to a spectral domain, please see U.S. Pat. App. Ser. No. 10/430,664 entitled "Method and System for Characterizing Microarray Output Data" filed on May 5, 2003

which is hereby fully incorporated by reference) in which spectral harmonics parameterize events of interest to a predetermined dynamical system (for which the applicable characteristics are input into the preconditioner unit. The operational phase components also include an active interferometric coupler 106 that convolves the preconditioned signal pattern and the previously generated expressor functions. The convolution is performed so as to interferometrically enhance portions of the preconditioned signal pattern associated with events of interest, if any, that are present within the preconditioned signal pattern. As explained more fully below, the convolution is performed via reverberant convergence so as to emulate active interferometric enhancement. Finally, the system also includes a resonant marker detector 108 that processes the convolved signal pattern so as to identify particular events of interest, if any, appearing within the convolved signal pattern.

With the exception of the platform array detector, which is a physical hardware component, all other components illustrated in FIG. 1 may be implemented in software, hardware, firmware or some combination thereof. In particular, each component may be a computer product operative to perform the functions described. In one example, each component is a software module operating within a single generally programmable computer. In other cases, the software modules are implemented using separate microprocessors or application specific integrated chips (ASICs). In still other examples, some of the components are implanted in software whereas others are completely hard-wired. As can be appreciated, a wide range of possible implementations is consistent with the invention and no attempt is made herein to describe all possible configurations.

Method steps associated with the open loop interferometric system of FIG. 1 will now briefly be summarized with reference to FIG. 2. Although these steps are advantageously performed by the system of FIG. 1, the steps can be performed by any other suitable system. Conversely, the system of FIG. 1, or portions thereof, may be employed to perform methods different from that which is illustrated in FIG. 2. The same is true for the various other figures of the patent application. In any case, at step 110, a signal pattern derived from a particular platform array detector is input and, at step 112, expressor functions designed to extract spectral invariants for events of interest detectable

by the particular platform array are input. Then, at step 114, the input signal pattern is preconditioned to convert the signal pattern to the spectral domain in which spectral harmonics parameterize events of interest to the aforementioned predetermined dynamical system. At step 116, the preconditioned signal pattern and the expressor functions are then
5 convolved using reverberant convergence so as to emulate an active interferometric enhancement of portions of the signal pattern associated with events of interest thus yielding a convolved signal pattern (also referred to herein as an enhanced signal pattern. Finally, at step 118, the convolved signal pattern is examined to identify events of interest therein.

10 It should be noted that a list of specific events of interest need not be input at step 112. Rather, the technique operates to detect possible events of interest present in the input pattern based solely on the input pattern and the previously-generated expressor functions. Hence, the technique of FIG. 2 is not merely a diagnostic technique that seeks to determine whether particular pre-determined events of interest are present in the input
15 signal pattern. This will be more readily apparent from the detailed examples which follow.

2. Exemplary Implementation

The mathematical equations performed by the various components of FIG. 1 or
20 during the various method steps of FIG. 2 will now be set forth in detail. In this example, quantum expressor functions are employed. However, as described below, other expressor functions can alternatively be used, with the equations modified as needed dependent upon factors such as signal to background strength, extraction core length of the events of interest being analyzed, platform coherence, and desired sensitivity.

25 The exemplary equations are particularly relevant for conditions where the background is 10 to 1000 times stronger than the signal.

Initially, during the design phase, expressor function generation unit 100 of FIG. 1 inputs platform array detector characteristics represented mathematically as:

$$\Psi[\Omega(N, M, T, \Lambda)]$$

where $\Omega(N, M, T, \Lambda)$ denotes a preconditioned extraction core corresponding to one or more events of interest. The indices $N (0:n)$, $M(0:m)$, $T(1:k)$, $\Lambda(0:p)$ respectively refer to the spatial, temporal and spectral dimensions of the physical or virtual arrayed platform described in FIG 11. Details of preconditioning the extraction core corresponding to event of interest are given in U.S. Pat. App. Ser. No. 10/430,664 entitled "Method and System for Characterizing Microarray Output Data" filed on May 5, 2003.

The Expressor Function Generation unit also inputs calibrated data (j exemplars) represented mathematically as:

$$\bigcup_j \Psi_1 \Psi_2 \Psi_3 \dots \Psi_j.$$

Based on the input calibrated data, the expressor function generation unit performs calculations provided below.

In some embodiments, Quantum Expressor Functions (QEF's) are calculated based upon the signal pattern based upon one or more events of interest. The QEF is generated by the steps of:

- (a) selecting a canonical coupled Spin Boson basis system by first conditioning a Hamiltonian for that system;
- (b) calculating harmonic amplitudes $|P_m|$ for the Hamiltonian
- (c) generating an order function (OF);
- (d) measuring the entrainment states of the OF using exemplars with ground truth data; and
- (e) modulating the OF using calibrated exemplars to yield the QEF

Fully characterized exemplars of the event of interest are used to develop a platform specific QEF. Hamiltonians are utilized as they provide a mathematical basis for determining the dynamical behavior of a system at each coordinate and at each momentum.

5 Hamiltonian systems are further characterized by kinetic and potential energy. A key property of Hamiltonian systems is that they are conservative and have no dissipation of energy during relaxation. The use of a Spin Boson Hamiltonian, which is a particular type of Hamiltonian systems, permits the exploitation of quantum stochastic resonance phenomenology. Hamilton's Equations and Hamiltonian functions pertain to well
10 understood concepts in dynamical systems theory and dynamical equations of motion. (See "Theory and Problems of Lagrangian Dynamics", Ed. Dare A. Wells, Schaum's Outline Series, McGraw-Hill Company, NY, 1967, pages 316-321; Elements of Hamiltonian Mechanics", Dter Haar, Pergamnon Press, 1960, pages 95-102; and "Statistical Mechanics", R.K. Pathria, Pergamon Press, Toronto, 1972, pages 6-7, 136-147).

15 The QEF encodes quantum noise to drive order in an asymmetric bistable quantum-mechanical system. The appearance of a resonance requires an asymmetry in the energies of the two states. A rate equation constructed for transitioning between the two states of a bistable system, such that the dynamics can be characterized in terms of transition rates $\Phi+$ and $\Phi-$ between two asymmetric quantum superposition states where
20 the drive frequency and interwell transition rates are much slower than intrawell relaxation rates. The signal to noise ratio (SNR) of such a superposition system is given by:

-16-

$$SNR = \frac{\pi}{4} \frac{\Phi_{+0}}{1 + \exp[\varepsilon_0 / \kappa_B T_0]} \left[\delta \left[\frac{\varepsilon}{\kappa_B T} \right] \right]^2 \varepsilon$$

Where κ_B is the Boltzmann's constant, T is the temperature, and the sinusoidally modulated asymmetry energy ε is given by:

$$\varepsilon = \varepsilon_0 + \delta_\varepsilon \times \cos \omega_s t$$

$$C(\tau) = \langle n_+(t+\tau | q_+, t) n_+(t | q_0, -\infty) \rangle$$

5

For the above bistable system, the power spectrum $S(\omega)$ may be represented by the Fourier transform of $C(\tau)$, containing a roughly Lorentzian broadband noise background and δ -function peaks at $\omega = 0$, the driving frequency ω_s , and its harmonics. A measured correlation function for the quantum noise is given by $C(t) = \langle n_{+i}(t) n_{+i}(t+\tau) \rangle$, where each

10 $n_{+i} = 0$ or 1, and the \langle , indicates an average over t over many data points i taken at equal intervals, and is given by

The probability of being in the + quantum state at t after being in the state q_0 is given by

$$n_+(t | q_0, -\infty).$$

15

A custom Hamiltonian, couples the above system to an ensemble of harmonic oscillators is given by:

$$H = \frac{1}{2} \varepsilon \sigma_z - \frac{1}{2} \hbar \Delta \sigma_x + \sigma_y \sum_{\eta} V_{\mu} (\xi_{\eta} + \xi_{\eta}^{\dagger}) + \hbar \sum_{\eta} \omega_{\eta}$$

In the above Hamiltonian, ϵ denotes the asymmetric energy, Δ is the tunneling matrix element, and σ_i are Pauli spin matrices, and ζ_η is a harmonic oscillator creation operator with frequencies ω_η .

An important aspect is to couple the transformed and preconditioned discrete microarray output to a mathematical model for a quantum-mechanical dynamical system with specific properties. Specific exemplary parameters for use in calculating the Hamiltonian are those proposed by A.J. Legett et al., *Reviews of Modern Physics*, 59, 1, 1987 and A.O. Caldiera and A.J. Legett *Annals of Physics*, 149, 374, 1983. The parameters are important for an offline simulation of this Spin Boson system on a digital computer. The empirical observables are then collected and used to estimate and compute spectral properties, which are actually used by the method.

Experimental or analytical valid parameters for the above system will work with the technique because the robustness of the method depends only on the bulk and qualitative properties shown by this system and the properties of its power spectral harmonics. This is an important because the method is substantially immune to nuances and specifics of the actual driving mathematical system.

The information about the effects of the environment is contained in the spectral density $J(\omega)$

$$J(\omega) = (\pi/2) \times \sum_{\eta} V_{\eta}^2 \delta(\omega - \omega_{\eta}).$$

The harmonic amplitudes determine the weights of δ spikes of an averaged spectral power density in an asymptotic state $S^{\infty}(\omega)$. ε refers to the coupling strength between the spin and boson systems, and P_0 defines the equilibrium state in the absence of driving force. Power Spectral Density (PSD) is a well understood concept is signal processing and basis for many computational algorithms. For a spectral signature, partitioned into bands of interest, power spectral density is formally as the set of measurements of average power in each spectral band, normalized by bandwidths. Formal definition can be found in "Cyclostationarity in Communications and Signal Processing", Ed. William Gardner, 1994, IEEE Press, NY, pages 46-47.

The power amplitudes η_m in the m th frequency component of asymptotic state space are calculated using

$$\eta_m(\Omega, \varepsilon) = 4\pi |P_m(\Omega, \varepsilon)|$$

and the phase shift is given by

$$\varphi_m(\Omega, \varepsilon) = \tan^{-1} \left[\frac{\text{Im}(P_m(\Omega, \varepsilon))}{\text{Re } P_m(\Omega, \varepsilon)} \right]$$

The analytic for the external force is given by

$$P_m(\Omega, \varepsilon) = \frac{\gamma}{\gamma - im\Omega} \frac{2\omega_c}{\pi} h(-im\Omega, \gamma)$$

The parameters γ , ε_0 are predetermined and are design specific. Typically, values of 0.001 and 0.0001 are used for γ and ε_0 respectively. In the above expression $|P_m|$ determine
 5 the weights of the δ spikes of the averaged spectral power density.

For some embodiments, the QEF is designed by matching the power spectral density (PSD) amplitude of preconditioned, extracted events of interest to that of the Spin Boson system described above so that stochastic and deterministic time scales match and so that the time scales couple back to noise statistics and degree of asymmetry. The
 10 technique employs a fully automated iterative conjugate gradient relaxation method for spectral matching between asymmetric base system and the transformed, preconditioned extraction core. The determination of the QEF depends on the specifics of bioelectronics substrates used for actual analysis. The method is however generalizable to all arrayed embodiments. In addition, the method is highly scalable to array dimensions (as the
 15 offline design trade-space time does not matter to computational complexity). As the system is an overdetermined coupled system, convergence criteria and stability of relaxation method directly relates to downstream resonance effectiveness.

Generation of Order Function

The order function (OF) of ground truth is generated as follows. The order
 20 function (OF) is for ground truth wherein ground truth represents a state wherein a positive signal to noise ratio (SNR) is expected for pixel intensities of selected exemplars used for

developing an QEF.

A classical Order Function (OF) is used with the following form:

$$5 \quad H(\theta) = - \sum_{k=-\infty}^{\infty} h_k Z_k e^{-2\pi i k \theta}$$

where $i = \sqrt{-1}$ and $h_k \equiv \int_0^1 d\theta h(\theta) e^{-2\pi i k \theta}$ and $0 < \theta < 1$.

The term

$h_k \equiv \int_0^1 d\theta h(\theta) e^{-2\pi i k \theta}$ is referred to as the Diado integral.

- 10 In this application, QEF are designed from a canonical dynamical system drawn from a family of exponential systems. Daido integral is a specific term used to construct an Order Function, which is then used to construct the QEF.

The OF is calculated using an order match which implies that the variance of the density function for a specific exponential family approaches 0 (within 0.000001 - 0.0001).

- 15 The free energy for the density function is given by

$$p(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \xi^a \xi_b e^{[i\lambda(x_a^b - x\delta_a^b)]} d\lambda$$

where ξ^a and ξ_b represent state vectors. X_a^b represents the random observable in

symmetric bilinear form, and λ denotes the characteristic function, calculated using extractions from exemplars with reference objects of interest known (see D.C. Brody and L.P. Hughston, "Geometry of Quantum Statistical Inference", Physics Review Letters, 77(14), pp. 2851-2855, 1996).

5 Determination of Entrainment States

The OF derivation uses results from Daido's theory of multibranch entrainment of coupled nonlinear oscillators, wherein a number of different entrained states co-exist. For exemplars, an *a priori* measurement of entrainment is performed. This is done by using an approximate Daido Integral() with Z_k = PSD maxima at regions where boundary of event
10 of interest > desired detection threshold (see Physics Review Letters, 77(7), 1406-1411.)
Pre-multiplier constants are used to ensure that Z_k meets the following tests:

- maxima power spectrum density (PSD) matches; and
- L_2 norm on even harmonics < e where e = NS-MRF Barrier assuming complete spatial randomness (CSR) assumptions discussed in U.S. Pat. No. 6,136,541, entitled
15 "Method and Apparatus for Analyzing Hybridized Biochip Patterns using Resonance Interactions Employing Quantum Expressor Functions all of which is hereby fully incorporated by reference". Note that NS-MRF refers to the nonstationary Markov random field representation.

The notion of entrainment states is exploited, in part, because the method treats the
20 spectral system embodied in an extraction core corresponding to the event of interest, as a special case of coupled nonlinear oscillators in equilibrium. However, due to device imperfections, signal degradation and other limitations, number of entrained binding states

(i.e., background and clutter conditions) may coexist. A PSD match is desired where the OF is Z-peaked (but single peaked around each event of interest centroid). Absence of a single peak implies imperfect or lack of presence of an event of interest. It also defines the resonance loci for this method (i.e., where maximum SNR enhancement) is obtained.

5 Ground Truth based Modulation of OF

The OF of ground truth is modulated to yield the QEF as follows. Under controlled calibration, as stated above, maximal SNR enhancement (optimal resonance) is achieved when OF yields a single peak. It is an important design point for matching PSD of coupling Spin Boson system to the synthetic QEF. The specific form of the QEF to be
10 used is the parameters of a generic OF shown above. So the exemplary method exploits two connotations of OF: (a) parametric form for the QEF (that is closer to the classical form) and (b) as exponential attractor for a dissipative system. The two OF's are then recoupled and convolved with spectrally transformed exemplar used for constructing the QEF.

15 The resulting QEF is given by:

$$\text{QEF}_{\text{MRC}_i} = \tilde{H}(\tilde{\theta}) = - \sum_{j=I_x}^{u_x} \sum_{k=I_y}^{u_y} \hat{h}_{k|v_{l=1,2,3}} Z_k e^{-2\pi k \theta}$$

Typically, only first three to twenty-five PSD peaks are considered for spectral matching.

Preferably the QEF is represented digitally using a matrix or array having the same number of elements in the spectrally transformed and preconditioned, extraction core to be
20 analyzed. In the exemplary embodiment this pertains to the preprocessing done to the post-hybridization microarray intensity output to get it into a form where it can be convolved with the Quantum Expressor Function.

A major limiting restriction in QSR that is avoided by the exemplary method pertains to matching the stochastic and deterministic time scales in "domain system" and the external coupling asymmetric dynamical system, since this has limited applicability to continuous data. By replacing the time scale match requirement with ensemble spatial statistics (statistical mechanics of the signal emitters responsible for generating the pattern of interest) expressed via the aforementioned generators an entirely new class of analysis for discrete systems is enabled. By deriving the condition that signal emitters need to satisfy to maximize QEF generator capacity, a properly constructed and conditioned QEF will be able to extract and enhance an entire class of interest to produce one or more expressor functions represented mathematically as

$$Q^0 : \vec{q}(q_1, q_2, \dots, q_p)$$

b. Preconditioning

15

The signal pattern output by platform array detector 102 is represented mathematically as:

$$I(N, M)$$

20

Using the input signal pattern, the Preconditioner unit 104 performs the mathematical calculations detailed in U.S. Pat. App. Ser. No. 10/430,664 entitled "Method and System for Characterizing Microarray Output Data" filed on May 5, 2003 which is hereby incorporated by reference, to generate the preconditioned output signal pattern represented mathematically as:

$$\Omega(N, M).$$

10 c. Convolution Coupling

Active interferometric coupler 106 performs the following mathematical calculations using the preconditioned signal pattern:

15 $\overline{f}^{(0)}$ is defined as a vector containing the preconditioned components from an event of interest,

and
$$\overline{f}^{(i)} = \overline{f}^{(i-1)} \overline{Q}^{(i)}$$

where $\overline{Q}^{(i)}$ represents is the QEF after i convolutions.

20

Thus
$$\overline{f}^{(1)} = \overline{f}^{(0)} \overline{Q}^{(1)}$$

$$\overline{f}^{(2)} - \overline{f}^{(1)} \overline{Q}^{(2)} = \overline{f}^{(0)} \overline{Q}^{(2)} \overline{Q}^{(1)}$$

25 where $\overline{Q}^{(0)}$ represents the QEF developed in the preceding step and (its dimensionless quantity)

and where $\overline{Q}^{(i)}$ represents the i -th perturbation to the QEF, induced by perturbing one of its spectral components.

for $k = 1$ to n

5

for $j = 1$ to 1000 (set to a large counter value)

perturb the k^{th} component of QEF as below

$$Q^j(k) = [Q^{j-1}(k) + jC_1 \sinh(w_0 j + C_1)]^+$$

10

where

$$[x]^+ = \begin{cases} x & \text{if } x \geq 0 \\ 0 & \text{if } x < 0 \end{cases}$$

and

15

$$C_1 = \frac{1}{3} \left(\frac{2\alpha}{360} \right); \square \text{ denotes a small constant;}$$

Let $w_0 =$ the variance computed from the values

$$\frac{\overline{f_{pc}}}{\text{Max}(\overline{f_{pc}})} \text{ where } f_{pc} \text{ denotes the preconditioned spectral vector}$$

20

corresponding to a known event of interest present in the arrayed pattern being analyzed.

2

As an example, f_{pc} refers to the spectral components of the positive control.

25

The convolution iteration can be expressed as:

$$R_{kj} = \frac{\overline{f}^{(j-1)} \cdot \overline{Q}^j}{f_{nc}^{(j-1)} \cdot \overline{Q}^j}$$

5 where f_{nc} refers to the spectral components of a canonical negative control, or preconditioned footprint of an event of interest known to be absent in the arrayed image.

After each convolution iteration check for monotonicity of

10

$$\frac{R_{kj+2}}{R_{kj+1}} > 1 \quad \text{AND} \quad \frac{R_{kj+1}}{R_{kj}} > 1$$

15

if yes → then exit loop to perform global QEF iterations (that means this particular k component is important, i.e we are diverging from the negative control.)

If no → then continue

end j loop

end k loop

20

Global QEF iterations may be performed if monotonic divergence is detected between the preconditioned extraction core being analyzed and the canonical negative control, then the same convolution coupling operations are repeated for all the spectral harmonics. The global QEF iterations are provided by:

25

A

Set $\overline{r}^0 = \overline{q}^{(j+2)}$

For $m = 1$ to 25 (chosen to be a small count value)

Compute

$$\bar{r}^m = \bar{r}^{m-1} + (m+j)C_1 \sin(\omega_0(m+j) + C_1) + mC_2 \sin(\omega_{1m} + C_2)$$

where ω_1 captures the variance of the components of $\frac{\bar{f}_{Nc}}{\text{Max}(\bar{f}_{Nc})}$

and

$$C_2 = C_1 + \varepsilon \left(\frac{\text{Parseval Avg from Pos. Con. PM}}{\text{Parseval Avg from Neg. Con PM}} \right)$$

where Parseval Avg. from Pos. Con. PM refers to the parseval number for a canonical event of interest known to be present, and Parseval Avg. from Neg. Con. PM refers to the parseval number for a canonical event of interest known to be absent.

and ε is chosen to be small, 0.0001.

Again after each coupler iteration compute the term

$$R_m = \frac{\left(\bar{f}^{j+m-1} \right) \cdot \left(\bar{r}^m \right)}{\left(\bar{f}_{Nc}^{j+m-1} \right) \cdot \left(\bar{r}^m \right)}$$

Successively compute $R_m, R_{m+1}, R_{m+2} \dots$

After each convolution iteration check if

$$\frac{R_{m+2}}{R_{m+1}} > 1 \text{ AND } \frac{R_{m+1}}{R_m} > 1$$

If the conditions of the above test are met, resonance is concluded and event of interest is called present.

If the monotonicity test fails, then the preconditioned test pattern is normalized using the expressions below.

B

5

if $\bar{f}^{(j)} - \bar{f}^{(j-i)} > \bar{f}_{pc}^{(g)} - \bar{f}_{Nc}^{(c)}$ for any component

$$\text{then } \bar{f}^{(j)} = \bar{f}^{(j)} - \left(\frac{\sum \bar{f}^{(j)} - \sum \bar{f}^{(j-1)}}{25} \right)$$

10

The above assumes an object with 25 spectral harmonics of interest.

The detailed equations for the coupler unit and resonance detector unit are given below:

15

1

for $j = 1$ to N

$$\Delta j \rightarrow j+1 = \frac{\sum (f_i \cdot \hat{Q}^{j+1,pm}) / \sum (NCF_i^{0,pm} \cdot Q^{j+1})}{\sum (f_i^{o,pm} \cdot Q^{j,pm}) / \sum (NCF_i^{g,pm} \cdot Q^{j,pm})}$$

$$Q^{j+1}_{j \neq k} = \hat{Q}^j$$

$$Q^{j+1}_{i=k} = \left[\begin{array}{c} \hat{Q}^j \\ i=k \end{array} + (\phi_c \cdot j) \sin(w_0 j + \phi_c) \right]$$

5

$$\text{Check } \frac{\Delta^2_{j-1,j+2}}{\Delta j} > 1$$

$$\frac{\Delta j + 1 \rightarrow j + 2}{\Delta j \rightarrow j + 1} > 1 \left| \frac{\Delta j \rightarrow j + 1}{\Delta j \rightarrow j} > 1 \right.$$

$$\phi_c = \frac{1}{3} \cdot \frac{2\pi}{360}$$

10

3

$$QEF_{r+1} = \left\{ QEF_r + A(j, r) + \frac{B}{r} \right\}$$

$$\text{where } B = f(w_1)$$

$$\text{and } W_1 = \sigma \left(\frac{\sqrt{\text{PSD}_{\text{pm,njc}}}}{\sqrt{\text{man PSD}_{\text{pm,njc}}}} \right)$$

$$A = \phi_c(j+r) \cdot \{ \sin(w_0(j+r) + \phi_c) \}$$

$$B = \phi_{c_1} r) \cdot \{ \sin(w, (r) + \phi_{c_1}) \}$$

5

$$\phi_{c_1} = \phi_c + \varepsilon \left(\frac{\sigma_1}{\sigma_2} \right) \{ = 0.0001 \}$$

$$W_0 = \sigma \left(\frac{\text{PSD}_{\text{QEF pc,pm}}}{\max(\text{PSD}_{\text{QEF,pc,pm}})} \right)$$

$$W_1 = \sigma \left(\frac{\text{PSD}_{\text{QEF,NC,pm}}}{\max(\text{PSD}_{\text{QEF,NC,pm}})} \right) \quad W_0 \approx W_1$$

10

d. Resonant Marker Identification

15

Finally, resonance marker detector 108 performs the following mathematical calculations using the convolved signal pattern to identify the events of interest within the convolved signal pattern.

20

The resonant iteration is terminated when

$$\frac{\Delta_{j-1,j+2}^2}{\Delta_j} > 1$$

$$\frac{\Delta_{j+1 \rightarrow j+2}}{\Delta_{j \rightarrow j+1}} > 1 \left| \frac{\Delta_{j \rightarrow j+1}}{\Delta_{j \rightarrow j}} > 1 \right.$$

5

or when iteration counter t exceeds preset " N " (e.g., 10^3 iterations) (for digital approximation to analog dynamics).

Preferably, the resonance interaction is performed digitally by applying a matrix representative of the resonance equation to a matrix representative of the resonance stimulus in combination with a matrix representative of the preconditioned extraction of event of interest.

The final result of interferometric analysis is the readout of locations wherein resonance has occurred and as identified by row and column number (i,j) .

Resonance Output Interpretation to Identify Gene Expression

For example, with regard to gene expression, once resonances peak are observed by applying a QEF to specific object extractions, the object addresses (k,l) of those locations are mapped into the physical feature or gene table (which contains the complimentary RNA or cDNA probe sequences associated with object locations) to thereby identify the gene being expressed, if any, present in the sample being analyzed. This is a simple table look-up resulting in a direct readout of the names of the expressed genes.

20

To summarize the open loop interferometric technique of FIGS. 1 and 2, the preconditioning of arrayed data to the spectral domain is performed independently prior to coupling with the expressor function. Hence, the reverberation convergence performed by the active interferometric coupler to achieve a resonance state is performed independent of preconditioning. The reverberations are an open loop process terminated upon detection of a predetermined condition (i.e. observation of a resonance marker.) The active interferometric coupler implements either a destructive or a constructive interference of two dynamical systems.

B. GOAL-DIRECTED INTERFEROMETRIC SYSTEM

FIG. 3 illustrates exemplary system components for the second exemplary implementation of the invention. As before, components employed only during a design phase are shown on the left and components employed during the actual analysis of an input signal are shown on the right. Some of the components of the system of FIG. 3 are the same as those shown in FIG. 1 and hence will be not described again in detail. Again, during a design phase, an expressor function generation unit 200 generates expressor functions based upon calibration data and based on the specific characteristics of a platform array detector 202 and during the operational phase, the platform array detector generates a signal pattern for analysis. However, no separate preconditioner unit is provided. Nor is any separate resonant maker detector provided. Rather, a single adaptive interferometric coupler 204 is provided that operates to simultaneously precondition the detected signal pattern to convert the arrayed signal pattern to a spectral domain while convolving the signal pattern and the expressor functions to interferometrically enhance of portions of the signal pattern and to identify events of interest, if any, within the preconditioned signal pattern. Again, with the exception of the platform array detector, which is a physical hardware component, all other components illustrated in FIG. 3 may

be implemented in software, hardware, firmware or some combination thereof.

Note that adaptive interferometric coupler 204 does not merely perform the operations previously described with respect components 104, 106 and 108 of FIG. 1. Rather, adaptive interferometric coupler 204 performs a different set of operations. Briefly, with the technique of FIG. 3, coupling intelligence is merged with preconditioning and the expressor functions are pre-coupled to the preconditioned functions, as will be apparent from the detailed example below. Convergent reverberation is performed simultaneously with preconditioning, which is now a closed loop process. Hence, with the technique of FIG. 3, preconditioning does not merely transform spatial arrayed data to spectral data but also transforms the data to a pre-determined state of a predetermined dynamical system. If that state is reached, then resonance is implicitly assumed to have occurred. Thus, completion of the adaptive interferometric coupling procedure implies the detection of resonant markers and so separate resonant marker detection unit is not required.

Method steps associated with the goal-directed interferometric system will now briefly be summarized with reference to FIG. 4. At step 206, a signal pattern derived from a particular platform array detector is input and, at step 208, expressor functions designed to extract spectral invariants for events of interest detectable by the particular platform array detector are input. Then, at step 210, the input signal pattern is preconditioned to convert the signal pattern to the spectral domain while convolving the signal with the expressor functions so as to emulate an active interferometric enhancement of portions of the signal pattern so as to identify events of interest therein. As with the technique described above, a list of specific events of interest need not be input during the operational phase. Rather, the technique operates to detect possible events of interest present in the input pattern based solely on the input pattern and the previously-generated expressor functions.

One of ordinary skill in the art will appreciate that the equations provided above in connection with the open loop interferometric system may be accordingly adjusted such that the resonant marker unit and the convolution coupling unit may be combined so that

the threshold check for resonance is performed during the post-convolution normalization.

C. SELF-ORGANIZING INTERFEROMETRIC SYSTEM

FIG. 5 illustrates exemplary system components for the third exemplary implementation of the invention. Unlike the systems thus far described, no separate design phase is required. Rather, all components operate during the actual analysis of an input signal. Again, some components are the same as those described above and hence will be not described again in detail. In use, a platform array detector 302 generates a signal pattern for analysis. The signal pattern is preconditioned by a preconditioner unit 304, which, as before, operates to convert the signal pattern to a spectral domain in which spectral harmonics parameterize events of interest to a predetermined dynamical system. The preconditioned signal pattern as well as characteristics of the platform array detector, calibration data and a set of canonical expressor functions are then all input by an expressor function adaptation unit 306. The canonical expressor functions are generalized expressor functions that have not been tailored to the particular platform being used. No separate design phase expressor function generation unit is provided. Nor is a separate resonant maker detector provided. Rather, expressor function adaptation unit 306 operates to simultaneously generate preconditioned expressor functions based on the preconditioned signal pattern and based on the canonical expressor functions while convolving the preconditioned signal pattern and the preconditioned expressor functions to interferometrically enhance portions of the signal pattern to identify events of interest. As before, with the exception of the platform array detector, which is a physical hardware component, all other components illustrated in FIG. 5 may be implemented in software, hardware, firmware or some combination thereof.

Note that expressor function adaptation unit 306 does not merely perform the operations previously described with respect to components 100, 106 and 108 of FIG. 1. Rather, with the technique of the self-organizing interferometric system, the coupling intelligence and the reverberation dynamics are pre-built into the expressor functions and so the expressor functions are not merely a representation of a spectral marker as with the technique of FIGS. 1 and 2 and with the technique of FIGS. 3 and 4. This will be more

readily apparent from the detailed example below. Also, although the preconditioning unit may be the same as in the technique of FIGS. 1 and 2, the preconditioned array now serves as a preconditioner to the expressor function to thereby produce a properly preconditioned expressor, which itself corresponds to the detection of resonant marker.

5 Hence, generating and outputting the properly preconditioned expressor function results in detection of the event of interest. As the expressor functions are tailored to the preconditioned array, they cannot be used again to process other signal patterns detected by the platform array detector. Also, as will be described in greater detail below, with the technique of the self-organizing interferometric system, the operations of the expressor
10 function adaptation unit operate in an internal closed loop.

Method steps associated with the self-organizing interferometric system will now briefly be summarized with reference to FIG. 6. At step 308, a signal pattern derived from a particular platform array detector platform is input and, at step 310, the signal patterns are preconditioned to convert the signal pattern to the spectral domain in which spectral
15 harmonics parameterize events of interest to the aforementioned predetermined dynamical system. At step 312, preconditioned expressor functions are then generated based on the preconditioned signal pattern and on the characteristics of the platform array detector and based on the events of interest. This is performed using a closed loop process employing reverberant convergence so as to emulate active interferometric enhancement of portions
20 of the original signal pattern associated with the events of interest. Hence, generation of the preconditioned expressor functions allows immediate detection of the events of interest without further processing. As before, no list of specific events of interest need be input during the operational phase.

One of ordinary skill in the art will appreciate that the equations provided above in
25 connection with the open loop interferometric system may be accordingly adjusted such that the modulation of the OF to generate a QEF is immediately succeeded by the convolution coupling.

D. ITERATIVE INTERFEROMETRIC SYSTEM

FIG. 7 illustrates exemplary system components for the fourth exemplary implementation of the invention. As before, components employed only during a design phase are shown on the left and components employed during the actual analysis of an input signal are shown on the right and components already described will be not described again in detail. During the design phase, an expressor function generation unit 400 generates expressor functions based upon calibration data and based on the specific characteristics of a platform array detector 402 and, during the operational phase, the platform array detector generates a signal pattern for analysis. The signal pattern is preconditioned by a preconditioner unit 404, which, as before, operates to convert the signal pattern to a spectral domain in which spectral harmonics parameterize events of interest to a predetermined dynamical system. An iterative interferometric coupler 406 convolves the preconditioned signal pattern and the previously-generated expressor functions so as to interferometrically enhance portions of the preconditioned signal pattern associated with events of interest that are present within the preconditioned signal pattern. However, unlike the technique of the open loop interferometric system of FIGS. 1 and 2, wherein the convolution coupler is a stand-alone unit that operates to generate a final convolved signal pattern, with the technique of FIG. 7, the iterative interferometric coupler operates under the control of an adaptive controller 408 to sequentially produce an iteratively convolved signal pattern. As explained more fully below, the adaptive controller operates to control the interferometric coupler to iteratively and selectively convolve expressor functions to the preconditioned signal pattern until a predetermined degree of convergence is achieved so as to allow identification of events of interest within the enhanced signal pattern. Again, with the exception of the platform array detector, all other components illustrated in FIG. 7 may be implemented in software, hardware, firmware or some combination thereof.

Method steps associated with the iterative interferometric system will now briefly be summarized with reference to FIG. 8. At step 410, a signal pattern derived from a particular platform array detector is input and, at step 412, expressor functions designed to

extract spectral invariants for events of interest detectable by the particular platform array detector are input. Then, at step 414, the input signal pattern is preconditioned to convert the signal pattern to the spectral domain spectral domain in which spectral harmonics parameterize events of interest to the aforementioned predetermined dynamical system. At
5 step 416, the preconditioned signal pattern and the expressor functions are then iteratively convolved under the control of the controller to achieve a reverberant convergence so as to emulate active interferometric enhancement of the signal pattern associated and to allow detection of events of interest. As before, no list of specific events of interest need be input during the operational phase.

10 One of ordinary skill in the art will appreciate that the equations provided above in connection with the open loop interferometric system may be accordingly adjusted such that multiple QEFs may be employed to achieve a desired resonance level and the most relevant QEF is chosen after each convolution if a desired resonance is not achieved.

15 E. GENERAL FEATURES

Exemplary embodiments are described above wherein arrayed data generated by a platform array detector is processed to identify events of interest therein. A wide variety of types of arrayed data maybe processed. FIG. 9 lists specific examples of types of arrayed data that may be processed. The examples shown include spatial 2-D data, spatial 1-D
20 data, point emitter data, temporal point emitter data, spatio-temporal point emitter data and spectral point emitter data. The different types of arrayed data may be separately processed or, as shown, combined to yield virtual arrays for processing. In FIG. 9, the symbol ψ generally represents a virtual array combiner operation, wherein individual spatial values are collected together into a single function or data array. For example, if sixteen
25 individual point emitters are provided, the data from the sixteen point emitters is combined or merged to yield a single 4 X 4 virtual array (represented, e.g., as $f(x,y)$). The symbol τ generally represents a temporal accumulation operation, wherein individual values are accumulated over time to yield a single time-varying function or data array. For example, if a single point emitters is provided, the point emitter may be sampled periodically to

accumulate values to populate a time-varying function (represented, e.g., as $f(t)$). In some cases, both virtual array and accumulation operations are performed to generate spatio-temporal data (represented, e.g., as $f(x,y,t)$).

More specifically, FIG. 9 illustrates:

5 (a) spatial data from a 2-D spatial array 500 represented in the form of a 2-D function $h(x,y)$;

(b) spatial data from a 1-D spatial array 502 represented the form of a 1-D function $k(x)$;

10 (c) spatial data from a group of point emitters 504 (with each point emitter_i, for $i = 1 \dots n$, providing a single non-time-varying value) assembled into a single 2-D function $h(x,y)$ via a virtual array combiner 506;

(d) temporal data from a single point emitter 508 accumulated over time via a temporal accumulator 510 to yield a single 1-D function $g(t)$;

15 (e) spatio-temporal data from a group of individual point emitter arrays 512 (with each point emitter_i, for $i = 1 \dots n$, providing a 2-D array non-time varying values) each separately accumulated over time via temporal accumulators 514 to yield individual functions $p(n,y,t)$, which are in turn assembled into a 2-D spatio-temporal function via a virtual array combiner 516; and

20 (f) spectral data from a group of individual spectral point emitters 518 (with each spectral point emitter_i, for $i = 1 \dots n$, providing an output function $f(\lambda)$ varying with wavelength) assembled into a 3-D virtual spectral array via virtual array combiner 520, with values then accumulated over time via temporal accumulators 522 to yield a 4-D function $g(x,y,\lambda,t)$.

25 Additionally, the various types of arrayed data ((a) - (f)) may be further combined into a larger virtual array (g) by virtual array combiner 524. Also, any of the types of arrayed data ((a) - (g)) may be further filtered via linear or non-linear filters 526, to yield filtered array functions (h). The final collection of data is represented in the figure as arrayed data 528. As can be appreciated, a wide variety of arrayed data may be input, combined and manipulated to yield individual multi-dimensional input functions for

processing by the above-described systems.

Also, a wide variety of preconditioner functions may be employed for use in preconditioning the arrayed data and a wide variety of expressor functions may be generated for use in processing the preconditioned arrays. FIG. 10 lists specific examples of types of expressor functions and types of preconditioning functions. The types of expressor functions are identified in terms of the type of noise associated with the expressor function. Examples of expressor functions include quantum expressor functions (QEFs), classical expressor functions (CEF), classical statistical noise expressor functions (SCNEFs), pseudorandom noise expressor functions (PRNEFs), systemic bias expressor functions and expressor functions based on polycyclostationary noise (PCS), cyclostationary noise (CS), stationary noise (SN), non-stationary noise (NS). Examples of preconditioner functions include 1-D Fourier functions, 2-D Fourier functions, N-D Fourier functions, a time division multiplexing (TDM) functions, wavelength division multiplexing (WDM) functions, frequency division multiplexing (FD) functions, radial basis functions, wavelet kernel functions, fractal functions and soliton functions. In general, any combination of expressor function type and preconditioner function type illustrated in the figure may be employed.

FIG. 11 illustrates an exemplary system 700 incorporating a biological platform array 702 that provides arrayed data to a software-based active interferometric analysis system 704. The platform array includes a solid support 706 upon which various probes 708 are attached via attachment chemistry portion 710. In the example of FIG. 11, the probes include one or more of cDNA, mRNA or oligonucleotide probes or proteins, peptides or oligopeptides. Following application of a biological sample, such as blood or urine, to the probes, a detector 712 detects a resulting pattern, which is then forwarded to the analysis system in the form of arrayed data. The analysis system exploits one of the general techniques described above to identify events of interest present in the biological sample. In this example, the events of interest are typically output in the form of one or more "gene calls".

A wide variety of different platform array detectors may be used to generate the

arrayed data. Examples of platforms detectors are listed in FIG. 12. The examples include optical platforms, biomolecular platforms, ionic platforms, biomechanical platforms, optoelectronic platforms, radio frequency platforms, and other electronic microdevices. Exemplary biomolecular spatial array platforms include: hybridized spotted cDNA
5 microarrays, synthesized oligonucleotide arrays, spotted oligonucleotide arrays, peptide nucleotide assays, single nucleotide polymorphism (SNP) arrays, carbohydrate arrays, glycoprotein arrays, protein arrays, proteomic arrays, tissue arrays, antibody arrays, antigen arrays, bioassays, sequencing microarrays, sequencing by hybridization (SBH) microarrays, siRNA duplexes, RNAi arrays glass-based arrays, nylon membrane arrays,
10 thin film arrays, polymer-substrate arrays, capillary electrophoresis arrays, genospectral arrays, electronic arrays, bead arrays, quantum dot arrays, glycan arrays, spotted wells, and spotted well plates. Typically, any of the foregoing platforms may be implemented as a microarray. Components of a typical-microarray are shown in FIG. 13, which include a substrate, a probe portion, a label portion, a bioassay portion, and a detector. Exemplary
15 substrates include glass, nylon, thin film, and polymer. Exemplary probes CDNA probes, spotted oligonucleotide probes and synthetic oligonucleotide probes. Exemplary labels 1-dye labels and 2-dye labels. Exemplary bioassay portions include prehybridization buffers, hybridization buffers and wash buffers. Exemplary detectors include laser scanners, confocal microscopy detectors, charge coupled devices (CCDs) and electronic readouts.
20 The substrate has a certain layout represented by feature size, various controls (positive, negative dye and alignment), and probe density.

FIG. 14 provides a summary of an exemplary technique of the invention. Briefly, the figure illustrates method for actively analyzing a signal pattern representative of arrayed data to identify events of interest therein. At step 700, a signal pattern
25 representative of arrayed data is input and, at step 702, resonance patterns are generated based on interference between synthetic noise and the signal pattern, in accordance with techniques already described. Thereafter, at step 704, resonances are detected within the resonance patterns associated with events of interest. The synthetic noise used at step 702 is preferably in the form of a quantum expressor function, a classical expressor function,

classical statistical noise, pseudorandom noise, a systemic bias or some combination thereof. The arrayed data may be, as already explained, in the form of a spatial 2-D array, a spatial 1-D array, an N-D array, a temporal point emitter array, a spatio-temporal point emitter array, spectral point emitter array or a virtual array constructed by combining
5 spatial separate point emitters.

The description of the exemplary embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art and the generic principles defined herein may be applied to other embodiments without the use of the inventive
10 faculty. Thus, the invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

-43-

CLAIMS:

What is claimed is:

1. A system for performing active interferometric analysis
5 using an expressor function to detect the presence of an event of interest within an arrayed signal pattern via a computationally induced interference mechanism.
2. The system of claim 1 implemented in software.
3. The system of claim 1 wherein the arrayed signal pattern
10 comprises either static data or dynamic data.
5. The system of claim 1 wherein the expressor function is a quantum expressor function.
6. The system of claim 1 wherein the arrayed signal pattern is
15 in the form of one or more of a spatial 1-D array, a spatial 2-D array, an N-D array, a temporal point emitter array, a spatio-temporal point emitter array, spectral point emitter array, or a virtual array constructed by combining spatial separate point emitters.
7. The system of claim 1 wherein the arrayed signal pattern is
20 generated from a device chosen from the group comprising: optical platforms, biomolecular platforms, ionic platforms, biomechanical platforms, optoelectronic platforms, radio frequency platforms, electronic microdevices.
8. The system of claim 1 wherein the arrayed signal pattern is
25 generated from a device chosen from the group comprising: hybridized spotted cDNA microarrays, synthesized oligonucleotide arrays, spotted oligonucleotide arrays, peptide nucleotide assays, single nucleotide polymorphism (SNP) arrays, carbohydrate arrays, glycoprotein arrays, protein arrays, proteomic arrays, tissue arrays, antibody arrays, antigen arrays, bioassays, sequencing microarrays, sequencing by hybridization

(SBH) microarrays, siRNA duplexes, RNAi arrays glass-based arrays, nylon membrane arrays, thin film arrays, polymer-substrate arrays, capillary electrophoresis arrays, genospectral arrays, electronic arrays, bead arrays, quantum dot arrays, glycan arrays, spotted wells, spotted well
5 plates.

9. The system of claim 1 wherein the expressor function is designed to reject any interfering noise and background clutter from events of interest.

10. The system of claim 9 wherein the expressor function is designed so as to extract spectral invariants of events of interest associated with an array platform device used to detect the arrayed signal pattern.

11. The system of claim 1 wherein the expressor function is comprised of frequency domain sequences, time domain sequences or spectral sequences, phase sequences or numeric sequences.

15 12. A system for performing active interferometric signal analysis of static data from an arrayed platform in software.

13. The system of claim 12 wherein the active interferometric analysis includes detection and quantitation analysis.

20 14. The system of claim 12 wherein the active interferometric analysis includes constructive interferometric analysis.

15. The system of claim 12 wherein the active interferometric analysis includes destructive interferometric analysis.

16. The system of claim 12 wherein the active interferometric analysis includes software emulation of wave-particle interactions.

25 17. The system of claim 12 wherein the active interferometric analysis includes software emulation of wave-wave interactions.

18. The system of claim 12 wherein the active interferometric analysis includes one or more of frequency domain, time domain, or phase domain analysis.

-45-

19. The system of claim 12 wherein the active interferometric analysis exploits iterative convergence to detect resonance events.

20. A system for performing active interferometric analysis by using reverberant convergence to detect resonance events.

5 21. The system of claim 20 exploiting quantum interferometric analysis.

22. The system of claim 21 wherein the quantum interferometric analysis is applied to one or more of a static spatial system, a static data from arrayed measurement platforms, dynamical systems, spatio-temporal systems and plasma systems.

23. The system of claim 20 wherein the active interferometric analysis exploits non-classical noise.

24. The system of claim 23 wherein the active interferometric analysis exploits one or more of non-Gaussian noise, ergodic noise, and quantum-mechanical noise.

25. The system of claim 20 wherein the active interferometric analysis exploits resonant interferometric signal analysis using a digital representation of spectral pulses.

26. The system of claim 20 wherein the active interferometric signal analysis exploits one or more of coherent, incoherent, synchronized, or asynchronous oscillations.

27. The system of claim 20 wherein the active interferometric analysis exploits time domain or frequency domain convolution operations.

28. The system of claim 20 wherein the active interferometric analysis exploits expressor functions to detect the presence of an event of interest via a computationally induced interference mechanism.

29. A method for actively analyzing a signal pattern representative of arrayed data to identify events of interest therein, the method comprising the steps of:

-46-

inputting a signal pattern representative of arrayed data;
generating resonance patterns based on interference between
synthetic noise and the signal pattern; and
detecting resonances within the resonance patterns associated with
5 events of interest.

30. The method of claim 29 wherein the synthetic noise is in the
form of one or more of a quantum expressor function, a classical expressor
function, classical statistical noise, pseudorandom noise, or a systemic
bias.

10 31. The method of claim 29 wherein the arrayed data is in the
form of one or more of a spatial 2-D array, a spatial 1-D array, an N-D
array, a temporal point emitter array, a spatio-temporal point emitter array,
spectral point emitter array or a virtual array constructed by combining
spatial separate point emitters.

15 32. The method of claim 29 further including the step of pre-
conditioning the signal pattern prior to the step of generating resonance
patterns.

33. The method of claim 32 wherein the step of pre-
conditioning the signal pattern is performed by applying one or more
20 preconditioning functions in the form of a 1-D Fourier function, a 2-D
Fourier function, an N-D Fourier function, a time division multiplexing
(TDM) function, a wavelength division multiplexing (WDM) function, a
frequency division multiplexing (FD) function, a radial basis function, a
wavelet kernel function, a fractal function, a soliton function.

25 34. The method of claim 29 wherein the arrayed data is
generated from a device chosen from the group comprising: optical
platforms, biomolecular platforms, ionic platforms, biomechanical
platforms, optoelectronic platforms, radio frequency platforms, electronic
microdevices.

-47-

35. The method of claim 29 wherein the arrayed data is generated from a device chosen from the group comprising: hybridized spotted cDNA microarrays, synthesized oligonucleotide arrays, spotted oligonucleotide arrays, peptide nucleotide arrays, single nucleotide polymorphism (SNP) arrays, carbohydrate arrays, glycoprotein arrays, protein arrays, proteomic arrays, tissue arrays, antibody arrays, antigen arrays, bioassays, sequencing microarrays, sequencing by hybridization (SBH) microarrays, siRNA duplexes, RNAi arrays glass-based arrays, nylon membrane arrays, thin film arrays, polymer-substrate arrays, capillary electrophoresis arrays, genospectral arrays, electronic arrays, bead arrays, quantum dot arrays, glycan arrays, spotted wells, spotted well plates.

36. A system for analyzing a signal pattern to identify events of interest within the signal pattern comprising:

- an expressor function input unit;
- a preconditioner unit;
- an active interferometric coupler; and
- a resonant marker detector.

37. A system for analyzing an arrayed signal pattern generated by an arrayed platform device to identify events of interest within the signal pattern comprising:

- an expressor function input unit for inputting expressor functions;
- a preconditioner unit for preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain in which spectral harmonics parameterize events of interest to a pre-determined dynamical system;

- a coupler unit for convolving the preconditioned signal pattern and the expressor functions so as to interferometrically enhance portions of the preconditioned signal pattern associated with events of interest, if any,

-48-

present within the preconditioned signal pattern; and

a resonant marker detector for identifying occurrence of events of interest within the enhanced signal pattern.

5 38. The system of claim 37 wherein the signal pattern is imaged and pixilated.

39. The system of claim 37 wherein the expressor functions are designed so as to be capable of extracting one or more of spatial, spatio-temporal or spectral invariants of events of interest associated with the array device.

10 40. A method for analyzing an arrayed signal pattern generated by an array device to identify events of interest within the signal pattern comprising the steps of:

inputting expressor functions capable of extracting spectral invariants of events of interest associated with the array device;

15 preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain;

convolving the preconditioned signal pattern and the expressor functions so as to interferometrically enhance portions of the preconditioned signal pattern associated with events of interest, if any, present within the preconditioned signal pattern; and

identifying events of interest within the enhanced signal pattern.

20 41. The method of claim 40 wherein the step of convolving the preconditioned signal pattern and the expressor functions includes the step of performing a reverberation convergence between the preconditioned signal pattern and the expressor functions to achieve a resonance state.

25 42. The method of claim 41 wherein the step of performing a reverberation convergence is performed using an open loop control process that terminates upon detection of a predetermined condition.

43. The method of claim 40 wherein the predetermined

-49-

condition is a resonant marker corresponding to an event of interest.

44. The method of claim 40 wherein the step of convolving the preconditioned signal pattern and the expressor functions includes the step of a destructive interference between the preconditioned signal pattern and the expressor functions.

45. The method of claim 40 the step of convolving the preconditioned signal pattern and the expressor functions includes the step of a constructive interference between the preconditioned signal pattern and the expressor functions.

46. A system for analyzing a signal pattern to identify events of interest within the signal pattern comprising:

an expressor function input unit; and

an adaptive interferometric coupler operative to perform signal preconditioning, convolution coupling and resonant marker detection using the expressor functions.

47. A system for analyzing an arrayed signal pattern generated by an arrayed platform device to identify events of interest within the signal pattern comprising:

an expressor function input unit for inputting expressor functions capable of extracting spectral invariants of events of interest associated with the arrayed signal pattern; and

an adaptive interferometric coupler for preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain to a spectral domain in which spectral harmonics parameterize events of interest to a pre-determined dynamical system while convolving the signal pattern and the expressor functions so as to interferometrically enhance of portions of the signal pattern and to identify events of interest, if any, within the signal pattern.

48. A method for analyzing an arrayed signal pattern generated

-50-

by an arrayed platform device to identify events of interest within the signal pattern comprising the steps of:

inputting expressor functions capable of extracting spectral invariants of events of interest associated with the array device; and

5 preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain to a spectral domain to a spectral domain in which spectral harmonics parameterize events of interest to a pre-determined dynamical system while convolving the signal pattern and the expressor functions so as to interferometrically enhance
10 portions of the signal pattern and to identify events of interest within the signal pattern.

49. The method of claim 48 wherein the step of preconditioning the signal pattern includes the step of performing a closed loop reverberation convergence between the signal pattern, as it is being
15 preconditioned, and the introduced expressor functions to achieve a resonance state, terminated upon detection of a predetermined condition.

50. The method of claim 48 wherein the predetermined condition is a resonant marker.

51. A system for analyzing a signal pattern to identify events of
20 interest within the signal pattern comprising:

 a preconditioner unit; and

 an expressor function adaptation unit operative to perform convolution coupling and resonant marker detection using canonical expressor functions.

52. A system for analyzing an arrayed signal pattern generated
25 by an arrayed platform device to identify events of interest within the signal pattern comprising:

 a preconditioner for preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain to a spectral

-51-

domain in which spectral harmonics parameterize events of interest to a pre-determined dynamical system; and

an expressor function adaptation unit for generating preconditioned expressor functions based on canonical expressor functions and based on the preconditioned signal pattern while extracting spectral invariants of events of interest associated with the array device and interferometrically enhancing portions the preconditioned signal pattern so as to identify events of interest, if any, within the signal pattern.

53. A method for analyzing an arrayed signal pattern generated by an array device to identify events of interest within the signal pattern comprising the steps of:

preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain to a spectral domain in which spectral harmonics parameterize events of interest to a pre-determined dynamical system; and

generating preconditioned expressor functions based on canonical expressor functions and based on the preconditioned signal pattern while extracting spectral invariants of events of interest associated with the array device and interferometrically enhancing portions the preconditioned signal pattern to identify events of interest, if any, within the signal pattern.

54. The method of claim 53 wherein the step of generating preconditioned expressor functions is performed so as to implicitly achieve a reverberation convergence between the preconditioned signal pattern and the expressor functions to achieve a resonance state.

55. The method of claim 53 wherein the step of generating preconditioned expressor functions is performed using a closed loop process.

56. A system for analyzing a signal pattern to identify events of interest within the signal pattern comprising:

-52-

an expressor function input unit;

a preconditioner unit;

an iterative interferometric coupler; and

5 an adaptive controller operative to control the iterative interferometric coupler to perform convolution coupling and resonant marker detection using the input expressor functions.

57. A system for analyzing an arrayed signal pattern generated by an arrayed platform device to identify events of interest within the signal pattern comprising:

10 an expressor function input unit for inputting expressor functions capable of extracting spectral invariants of events of interest associated with the array device;

a preconditioner for preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain to a spectral
15 domain in which spectral harmonics parameterize events of interest to a pre-determined dynamical system;

an iterative interferometric coupler for convolving the preconditioned signal pattern and the expressor functions so as to interferometrically enhance portions of the preconditioned signal pattern
20 associated with events of interest, if any, present within the preconditioned signal pattern; and

an adaptive controller for controlling the coupler to iteratively and selectively convolve expressor functions to the preconditioned signal pattern until a predetermined degree of convergence is achieved so as to
25 identifying events of interest within the enhanced signal pattern.

58. A method for analyzing an arrayed signal pattern generated by an arrayed platform device to identify events of interest within the signal pattern comprising the steps of:

inputting expressor functions capable of extracting spectral

-53-

invariants of events of interest associated with the array device;

preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain; and

iteratively and selectively convolving the preconditioned signal pattern and the expressor functions so as to interferometrically enhance portions of the preconditioned signal pattern associated with events of interest, if any, present within the preconditioned signal pattern until a predetermined degree of convergence is achieved so as to identifying events of interest within the enhanced signal pattern.

59. The method of claim 58 wherein the step of iteratively and selectively convolving the preconditioned signal pattern and the expressor functions is performed by repeatedly convolving a single fixed expressor function to the preconditioned signal pattern using reverberant convergence until the predetermined degree of convergence is achieved.

60. The method of claim 58 wherein the step of iteratively and selectively convolving the preconditioned signal pattern and the expressor functions is performed by selectively convolving a set of different fixed expressor functions to the preconditioned signal pattern using reverberant convergence until the predetermined degree of convergence is achieved.

61. The method of claim 58 wherein the step of iteratively and selectively convolving the preconditioned signal pattern and the expressor functions is performed by selectively modifying and then convolving a dynamic expressor function to the preconditioned signal pattern using reverberant convergence until the predetermined degree of convergence is achieved.

62. A system for analyzing an arrayed signal pattern generated by an arrayed platform device to identify events of interest within the signal pattern comprising:

means for inputting expressor functions capable of extracting

-54-

spectral invariants of events of interest associated with the array device;

means for preconditioning the arrayed signal pattern so as to convert the arrayed signal pattern to a spectral domain; and

5 means for iteratively and selectively convolving the preconditioned signal pattern and the expressor functions so as to interferometrically enhance portions of the preconditioned signal pattern associated with events of interest, if any, present within the preconditioned signal pattern until a predetermined degree of convergence is achieved so as to identifying events of interest within the enhanced signal pattern.

10 63. A computer code product for actively analyzing a signal pattern representative of arrayed data to identify events of interest therein, comprising:

computer code that inputs a signal pattern representative of arrayed data;

15 computer code that generates resonance patterns based on interference between synthetic noise and the signal pattern; and

computer code that detects resonances within the resonance patterns associated with events of interest.

20 64. A computer code product for analyzing an arrayed signal pattern generated by an arrayed platform device to identify events of interest within the signal pattern, comprising:

25 computer code that preconditions the arrayed signal pattern based on input expressor functions so as to convert the arrayed signal pattern to a spectral domain in which spectral harmonics parameterize events of interest to a pre-determined dynamical system;

computer code that convolves the preconditioned signal pattern and the expressor functions so as to interferometrically enhance portions of the preconditioned signal pattern associated with events of interest, if any, present within the preconditioned signal pattern; and

computer code that identifies the occurrence of events of interest within the enhanced signal pattern.

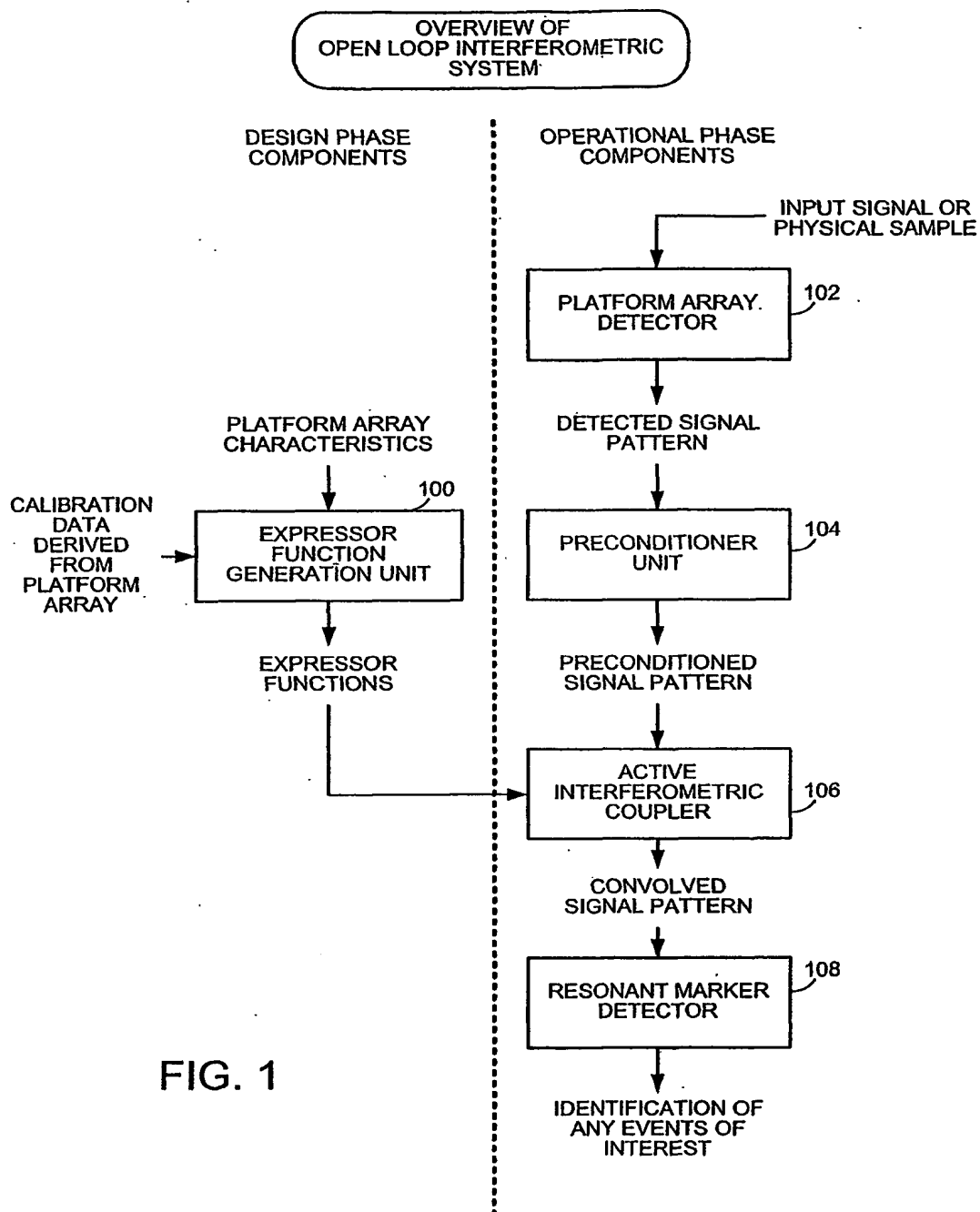


FIG. 1

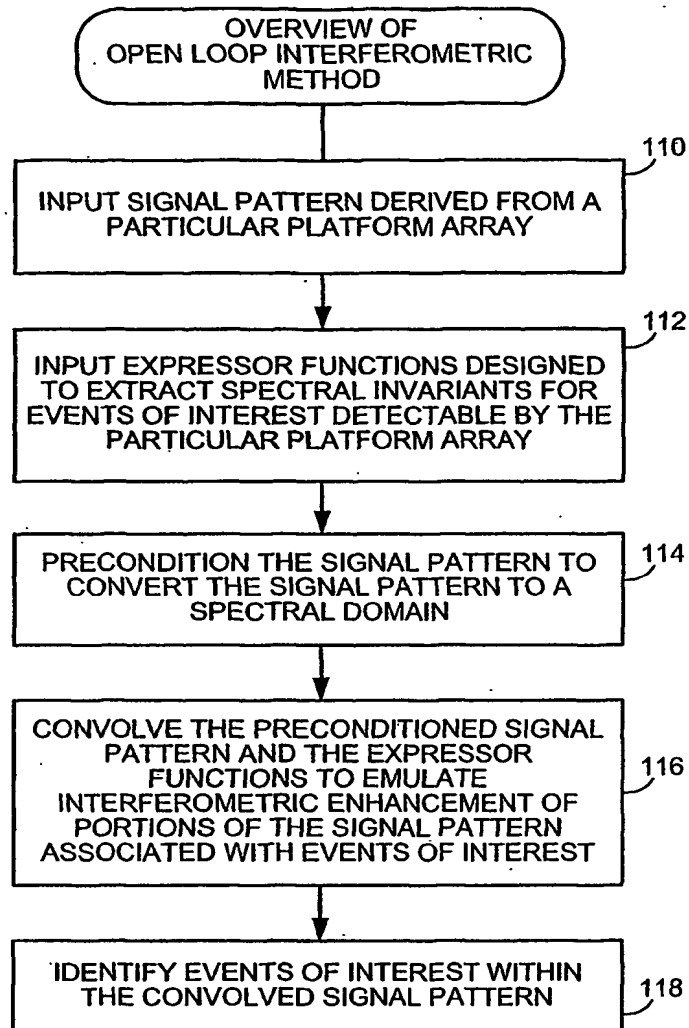


FIG. 2

3/14

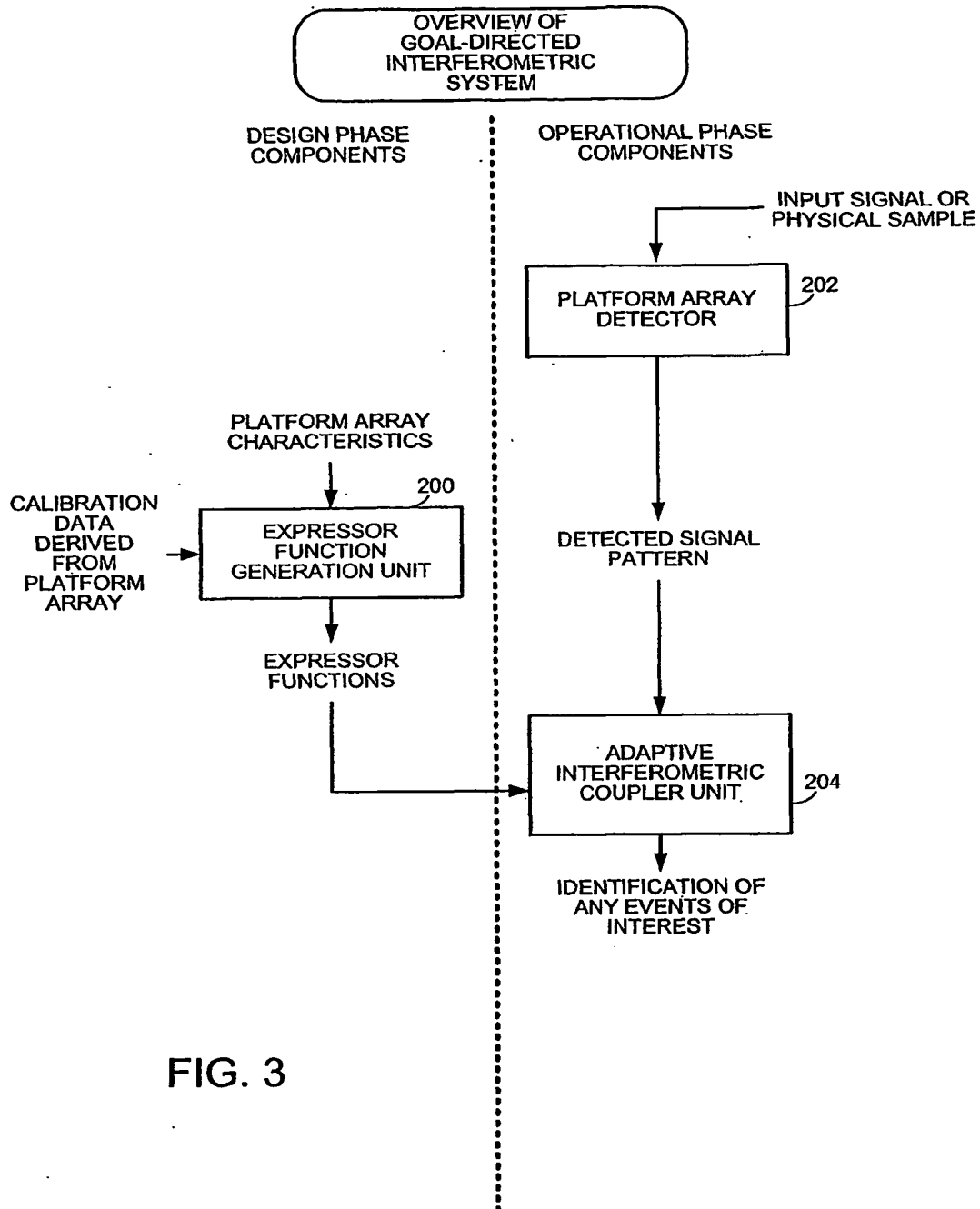


FIG. 3

4/14

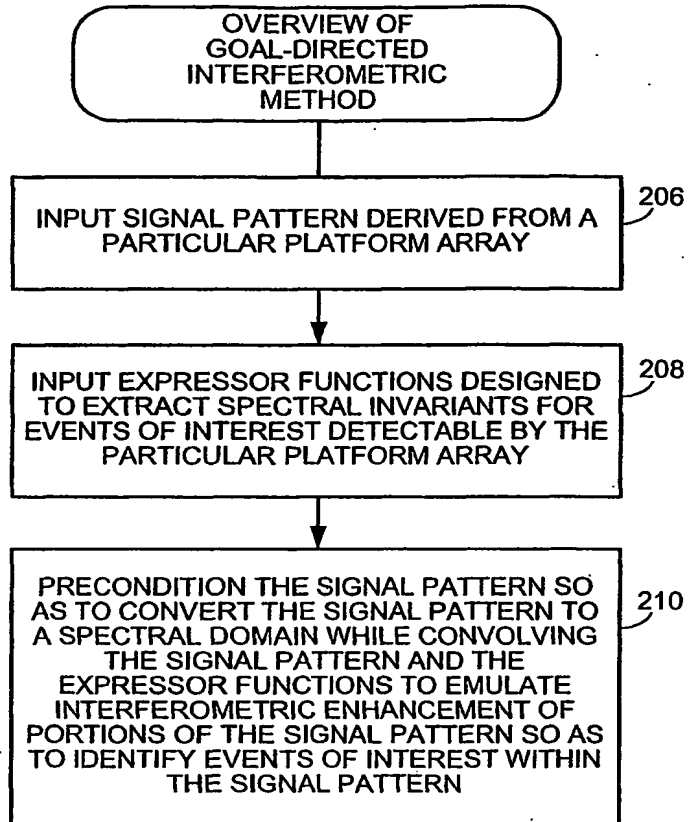


FIG. 4

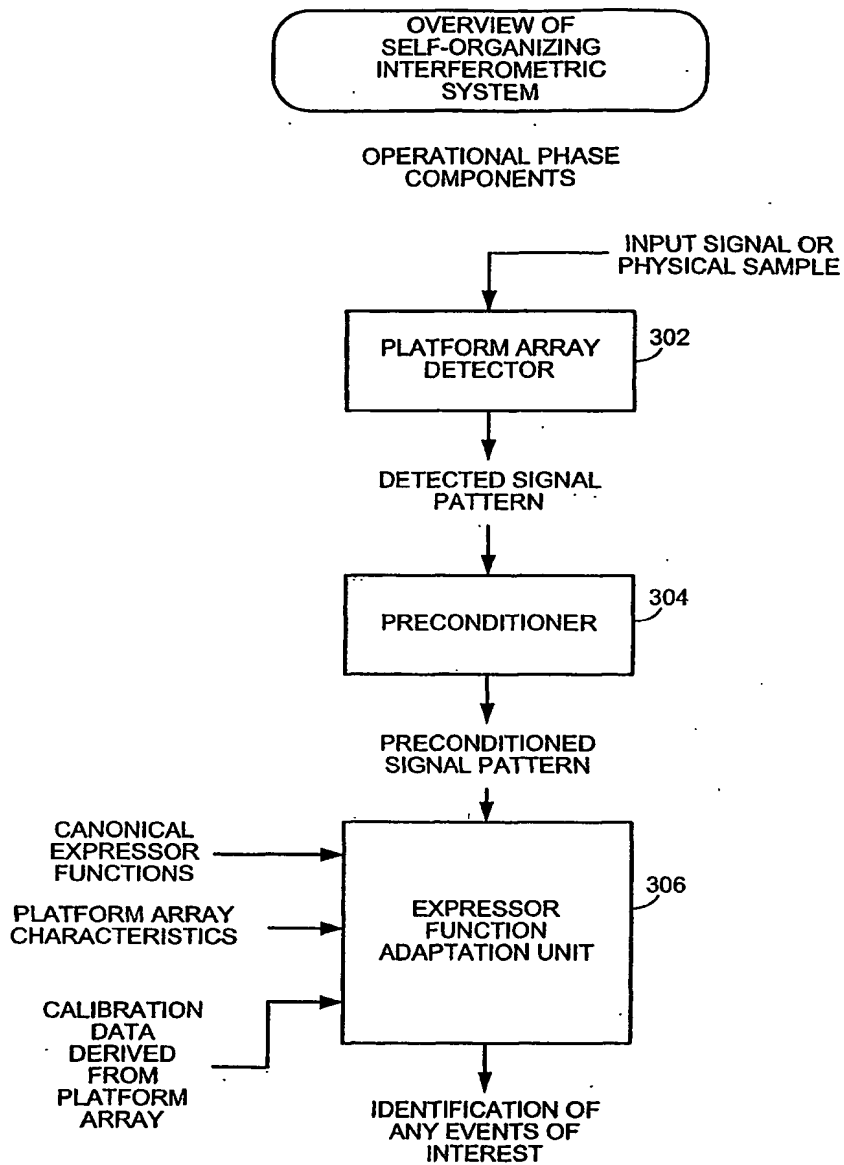


FIG. 5

6 / 14

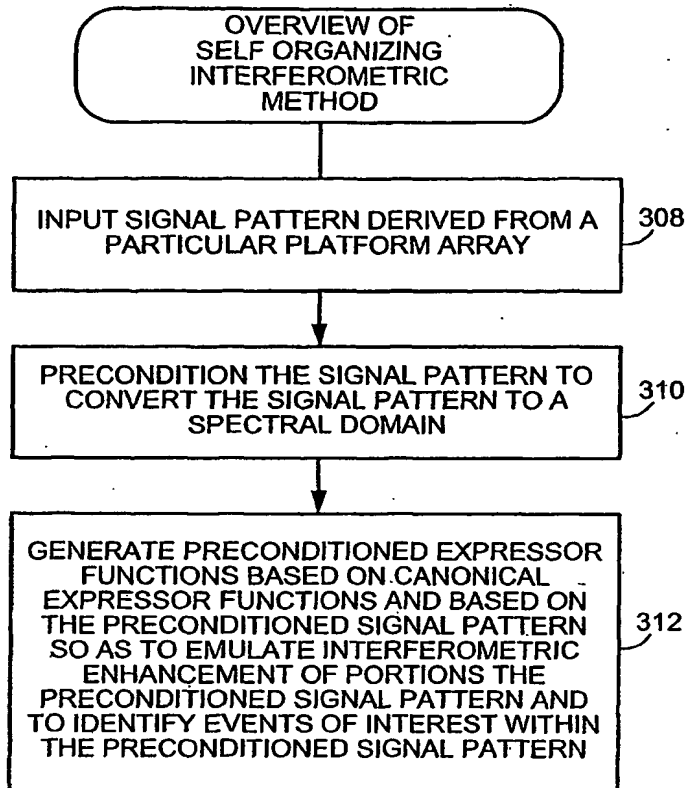


FIG. 6

7/14

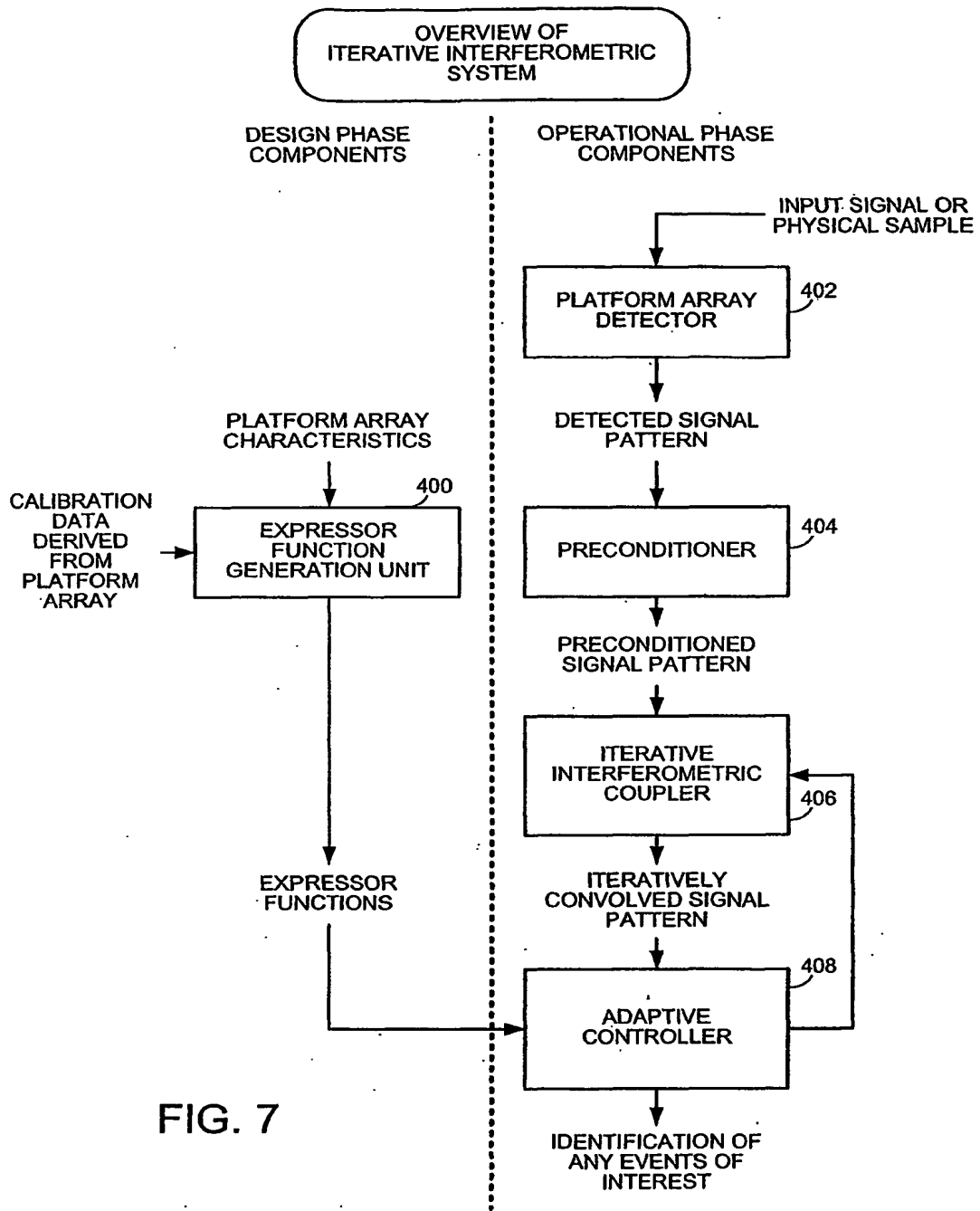


FIG. 7

8/14

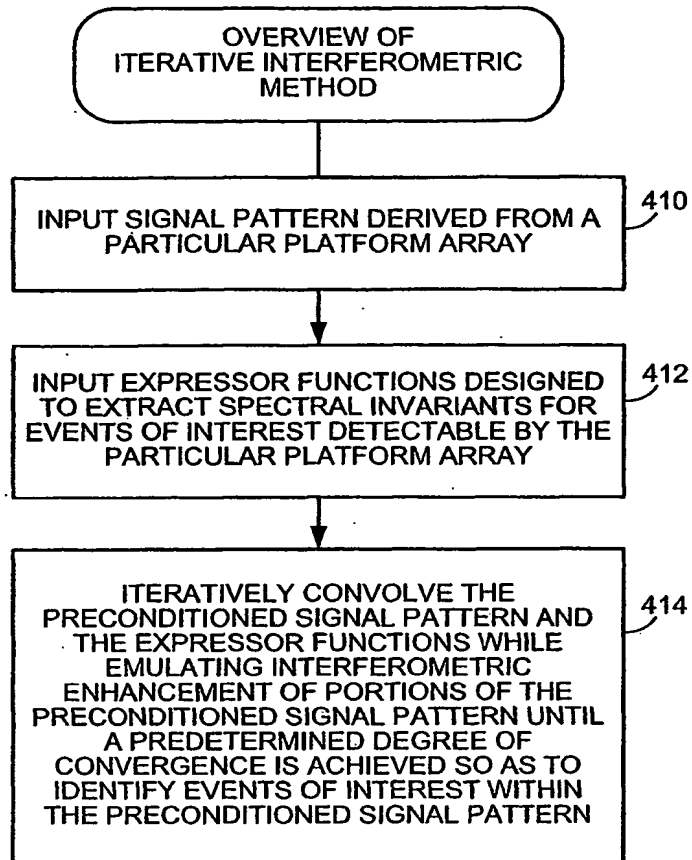


FIG. 8

Types of Array Data

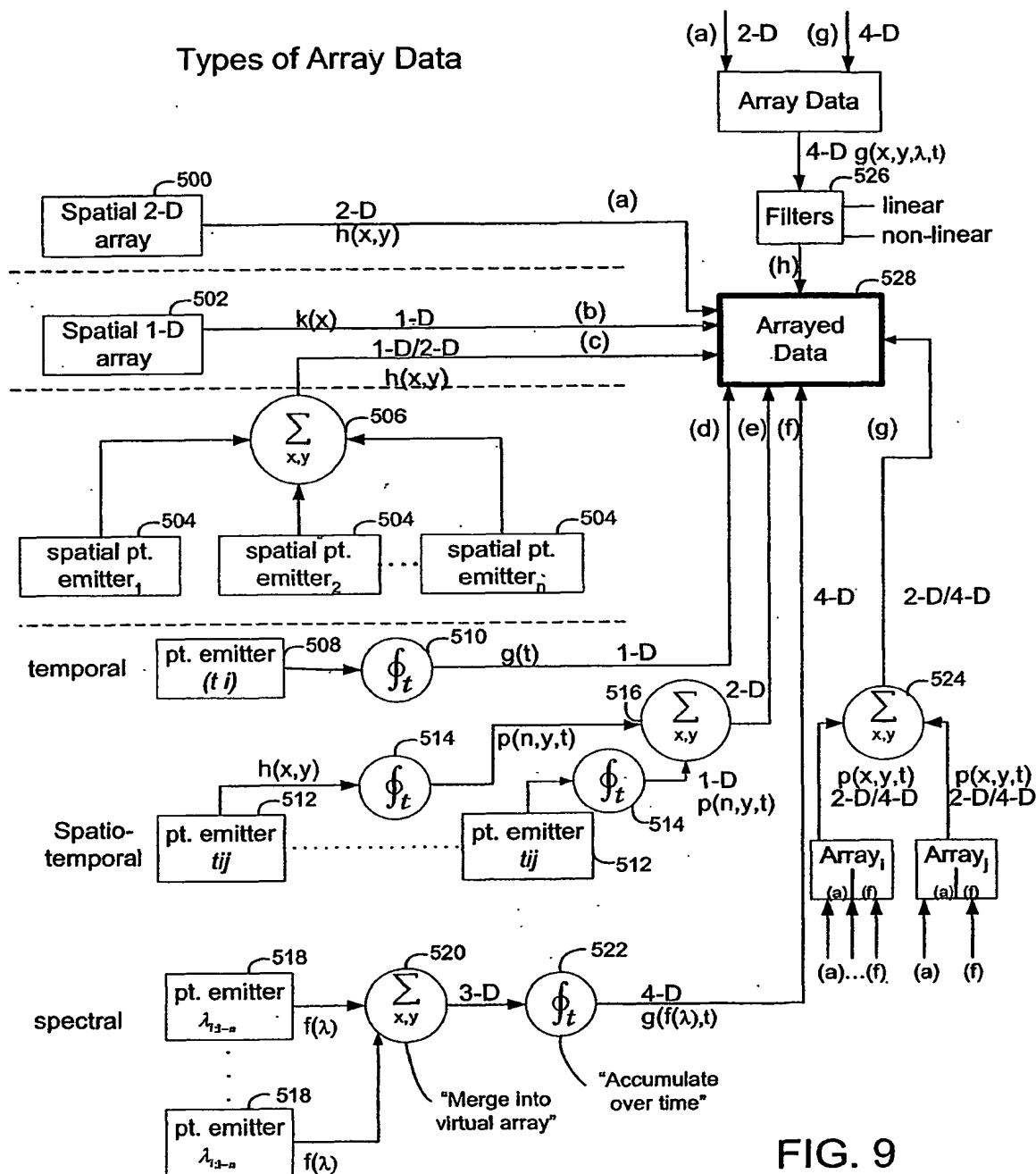


FIG. 9

Application Specific Expressor Function Building Blocks

FIG. 10

Express Function Types		Preconditioner Types						
		Window (TDM, WDM, FDM)		Radial Basis Function Kernel		N-D Fourier Soliton		
		1-D Fourier	2-D Fourier	1-D	2-D	Fractal	N-D	
QEF								
CEF								
PRN								
Systemic Bias								
Stationary								
NS								
CS								
PCS								

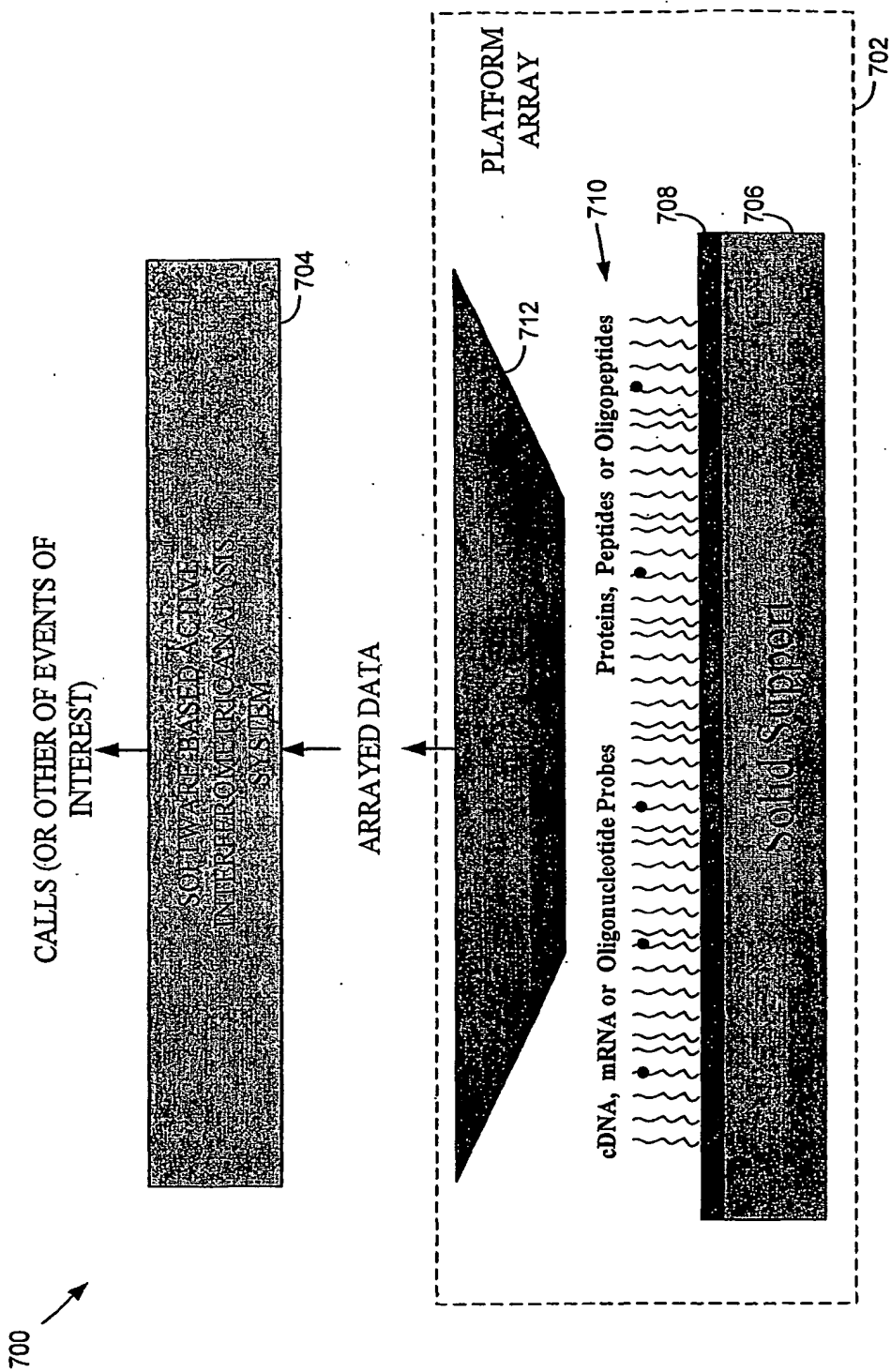


FIG. 11

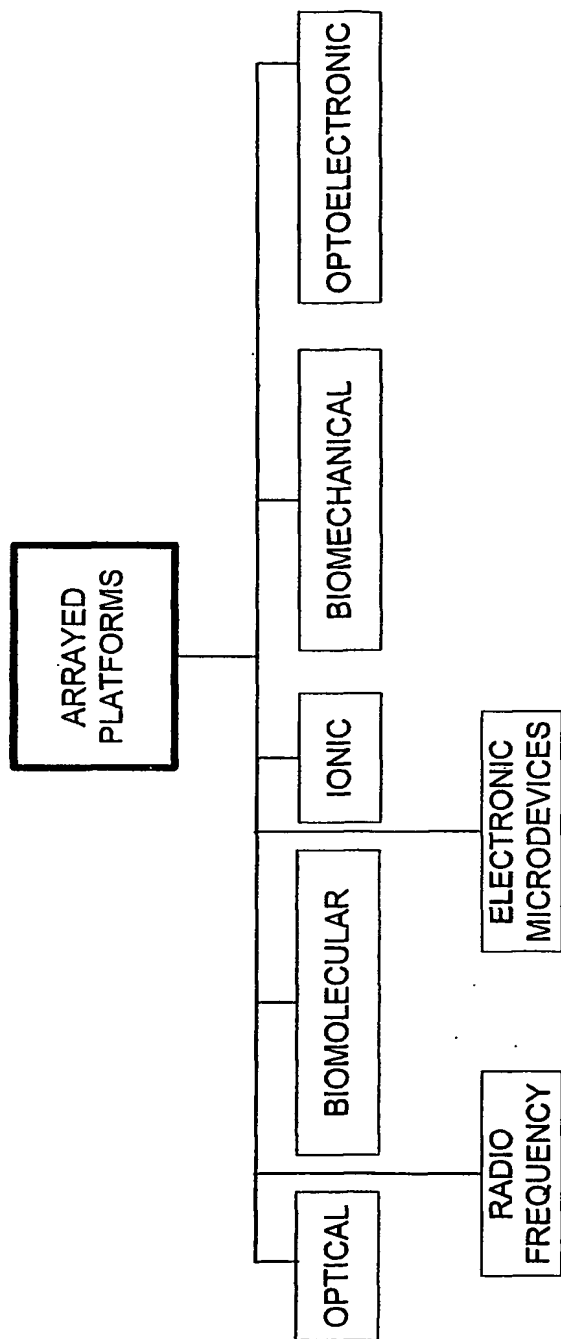


FIG. 12

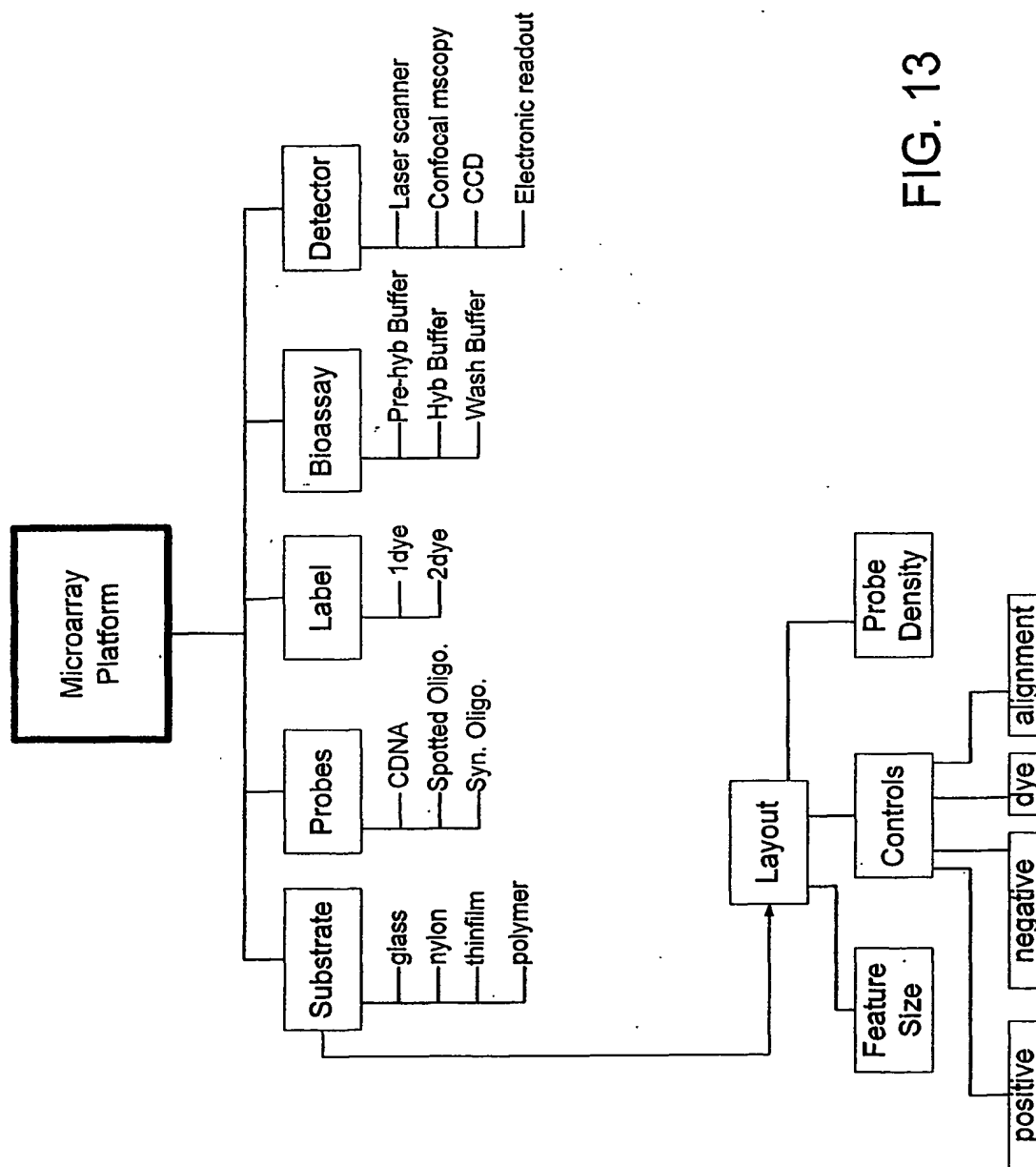


FIG. 13

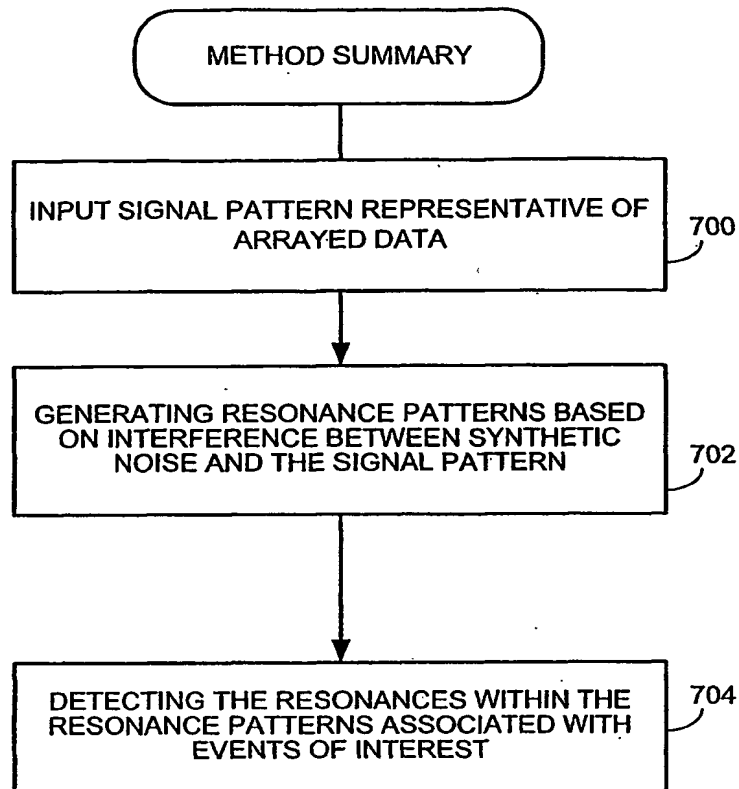


FIG. 14

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
25 November 2004 (25.11.2004)

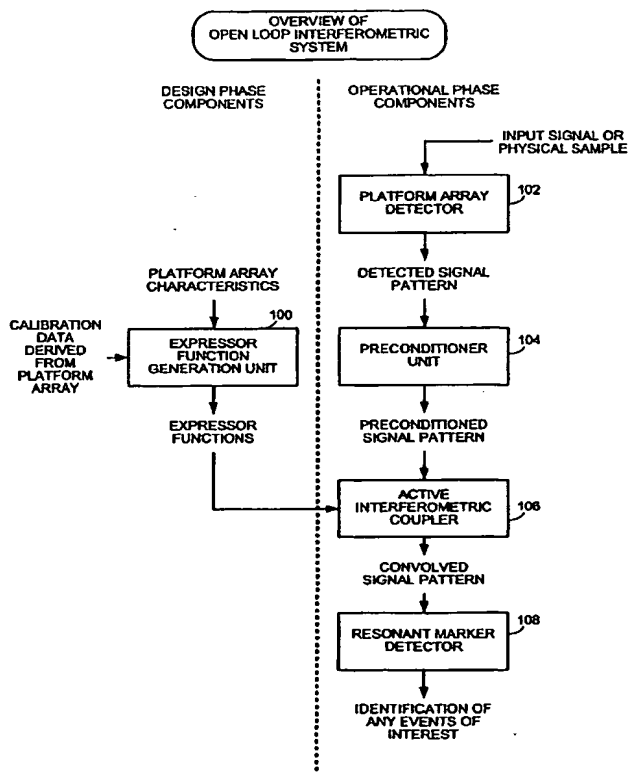
PCT

(10) International Publication Number
WO 2004/102456 A3

- (51) International Patent Classification⁷: **G06F 19/00**
- (21) International Application Number:
PCT/US2003/021525
- (22) International Filing Date: 9 July 2003 (09.07.2003)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
60/395,074 9 July 2002 (09.07.2002) US
60/399,227 29 July 2002 (29.07.2002) US
60/408,057 3 September 2002 (03.09.2002) US
60/408,844 5 September 2002 (05.09.2002) US
60/440,253 15 January 2003 (15.01.2003) US
- (71) Applicant (for all designated States except US): **VIAL-OGY CORP.** [US/US]; 2400 Lincoln Avenue, Altadena, CA 91001 (US).
- (72) Inventor; and
(75) Inventor/Applicant (for US only): **GULATI, Sandeep** [US/US]; 5467 La Forest Drive, La Canada Flintridge, CA 91011 (US).
- (74) Agent: **KUKKONEN, Carl, A., III**; 2400 Lincoln Avenue, Altadena, CA 91001 (US).
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE,

[Continued on next page]

(54) Title: **ACTIVE INTERFEROMETRIC SIGNAL ANALYSIS IN SOFTWARE**



(57) **Abstract:** Techniques are provided for performing active interferometric signal analysis in software. The techniques exploit expressor functions designed to extract spectral invariants of events of interest associated with an arrayed platform device used to detect the signal pattern to be analyzed. Various techniques for generating expressor functions are also provided. Depending upon the implementation, the techniques provide for both detection and quantitation analysis by exploiting either constructive or destructive interferometric analysis using reverberant convergence to detect resonance events. The techniques achieve software emulation of wave-particle interactions and wave-wave interactions and can operate in either the frequency domain or the phase domain. The techniques may be used for analyzing static spatial systems, static data from arrayed measurement platforms, dynamical systems, spatio-temporal systems or plasma systems.

WO 2004/102456 A3



ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO,
SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM,
GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(88) Date of publication of the international search report:

27 January 2005

Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 03/21525

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06F19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G06F C12Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, BIOSIS, INSPEC, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 136 541 A (GULATI SANDEEP) 24 October 2000 (2000-10-24) cited in the application column 7, line 30 - column 8, line 33 column 10, line 13 - column 27, line 5 figures 2-5	1-64
X	US 6 142 681 A (GULATI SANDEEP) 7 November 2000 (2000-11-07) cited in the application abstract column 1, line 64 - column 3, line 27 column 6, line 21 - column 8, line 9 figures 1-3	1-64
A	US 5 784 162 A (BUCKWALD ROBERT A ET AL) 21 July 1998 (1998-07-21) column 1, line 13 - column 6, line 62 figures 1,2	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *G* document member of the same patent family

Date of the actual completion of the international search

7 December 2004

Date of mailing of the international search report

15/12/2004

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Godzina, P

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 03/21525

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 6136541	A	24-10-2000	AT 280415 T	15-11-2004
			AU 5585900 A	21-09-2000
			DE 60015075 D1	25-11-2004
			EP 1145181 A2	17-10-2001
			EP 1406201 A2	07-04-2004
			WO 0052625 A2	08-09-2000
			US 2004111219 A1	10-06-2004
			US 2004064261 A1	01-04-2004
			US 6671625 B1	30-12-2003
US 6142681	A	07-11-2000	AT 280416 T	15-11-2004
			AU 3368600 A	14-09-2000
			DE 60015092 D1	25-11-2004
			EP 1157347 A2	28-11-2001
			EP 1406200 A2	07-04-2004
			WO 0051056 A2	31-08-2000
			US 2004063136 A1	01-04-2004
			US 6780589 B1	24-08-2004
US 5784162	A	21-07-1998	US 5539517 A	23-07-1996
			EP 0830564 A1	25-03-1998
			IL 121426 A	29-02-2000
			JP 11500832 T	19-01-1999
			JP 3280035 B2	30-04-2002
			US 6075599 A	13-06-2000
			WO 9721979 A1	19-06-1997
			US 6066459 A	23-05-2000
			US 6007996 A	28-12-1999
			US 6690817 B1	10-02-2004
			US 6556853 B1	29-04-2003
			US 6165734 A	26-12-2000
			US 5936731 A	10-08-1999
			US 5817462 A	06-10-1998
			US 2001033364 A1	25-10-2001
			US 5719024 A	17-02-1998
			US 5856871 A	05-01-1999
			US 5991028 A	23-11-1999
			US 5835214 A	10-11-1998
			US 5798262 A	25-08-1998
			US 6018587 A	25-01-2000
			US 6198532 B1	06-03-2001
			US 6055325 A	25-04-2000
			US 5912165 A	15-06-1999
			US 5906919 A	25-05-1999
			US 5995645 A	30-11-1999
			EP 0767361 A2	09-04-1997
			GR 3033470 T3	29-09-2000